ECE36800 Programming Assignment #2

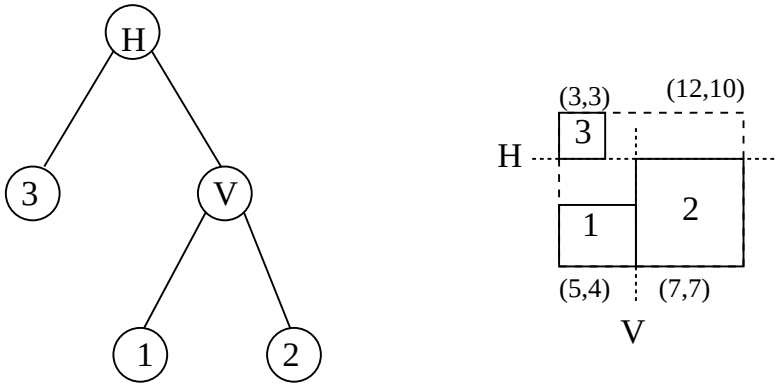
This assignment covers learning objective 1: An understanding of basic data structures, including stacks, queues, and trees; learning objective 5: An ability to design and implement appropriate data structures and algorithms for engineering applications.

You will implement a program to compute the "2D packing" of *rectangular blocks*. The "packing" of the rectangular blocks must follow a topology described using a strictly binary tree. A strictly binary tree is a binary tree where a node has either 0 or 2 child nodes. A node with 0 child nodes is a leaf node and a node with 2 child nodes is an internal (non-leaf) node.

1 "Packing"

In this strictly binary tree, each leaf node represents a rectangular block. Each internal node of the binary tree represents a partitioning of two groups of rectangular blocks by a horizontal cutline or a vertical cutline. Let xHy (xVy) denote a (sub)tree, whose root node is a horizontal cut H (a vertical cut V). The left and right subtrees of H (V) are x and y, respectively. Assume that xHy means x is above and y is below the horizontal cut, and xVy means x is to the left of and y is to the right of the vertical cut.

In the following figure, we show a "packing" of three rectangular blocks based on a given strictly binary tree representation. Assume that the dimensions (width, height) of the three rectangular blocks 1, 2, and 3 are respectively $(5,4)$, $(7,7)$, and $(3,3)$.



(a) A binary tree (b) The corresponding packing

Each subtree (whose root node is an internal node) is enclosed by a *smallest rectangular room*. The smallest room containing the subtree $1V2$, for example, is of dimensions $(12,7)$. The smallest room containing the tree $3H(1V2)$ is of dimensions $(12,10)$. This room is partitioned into two smaller rooms: The top room is of dimensions $(12,3)$ and it contains the rectangular block 3. The

bottom room is of dimensions $(12,7)$ and it contains the rectangular blocks 1 and 2. We place the lower left corner of each rectangular block at the lower left corner of its room.

Assume that the lower left corner of the smallest room containing all rectangular blocks is at coordinates $(0,0)$ (x- and y-coordinates). As mentioned earlier, this room of dimensions $(12,10)$ is partitioned into a top room of dimensions $(12,3)$ and a bottom room of dimensions $(12,7)$ because the root node has a horizontal cut.

Note that the smallest rectangular room containing rectangular block 3 is of dimensions $(3,3)$, and it can be contained in the top room of dimensions $(12,3)$. The smallest rectangular room containing the V node is of dimensions $(12,7)$ and it can be contained in the bottom room of dimensions $(12,7)$.

The bottom room, should also have its lower left corner at coordinates $(0,0)$. As the bottom room is of height 7, the top room should have its lower left corner at coordinates $(0,7)$.

The bottom room is partitioned into a left room of dimensions $(5,7)$ and a right room of dimensions $(7,7)$ because the corresponding non-leaf node has a vertical cut. Note that the smallest rectangular room containing rectangular block 1 is of dimensions $(5,4)$, and it can be contained in the bottom-left room of dimensions $(5,7)$. Of course, the smallest rectangular room containing rectangular block 2 is of dimensions $(7,7)$, and it can also be contained in the bottom-right room of dimensions $(7,7)$.

As the bottom room has its lower left corner at coordinates $(0,0)$, the bottom-left room should have its lower left corner at coordinates $(0,0)$. Because the bottom-left room is of width 5, the bottom-right room should have its lower left corner at coordinates $(5,0)$.

Rectangular block 1, which is contained in the bottom-left room, should therefore have its lower left corner at coordinates $(0,0)$. Rectangular block 2, which is contained in the bottom-right room, should have its lower left corner at coordinates $(5,0)$. Rectangular block 3, which is contained in the top room, should have its lower left corner at coordinates $(0,7)$.

Note that even though there is space directly above block 1 to accommodate block 3, block 3 has to stay above the horizontal cutline in the "packing," as shown in the figure. That is the reason we use "packing" instead of packing in this document. **We do not really pack the rectangular blocks tightly.**

For this programming assignment, you are given a strictly binary tree representation of a "packing" of rectangular blocks. You have to determine the smallest room to enclose all rectangular blocks and their coordinates, under the conditions that the cutlines are respected and that the lower left corner of a rectangular black coincides with the lower left corner of its room.

2 Deliverables

In this assignment, you have to develop your own include files that define the structures you want to use and declare the functions you need to manipulate the structures. You should define these functions in your source files. These files should be compiled into an executable with the following command:

```
gcc -O3 -std=c99 -Wall -Wshadow -Wvla -pedantic *.c -o pa2
```

If you supply a `Makefile`, we will generate the executable `pa2` with the following command:

```
make pa2
```

The executable `pa2` would be invoked as follows:

```
./pa2 in_file out_file1 out_file2 out_file3
```

The executable loads the strictly binary tree from `in_file` and saves the results into three output files: `out_file1`, `out_file2`, and `out_file3`.

The input file `in_file` contains the strictly binary tree and the dimensions of the rectangular blocks. The `in_file` corresponds to a pre-order traversal of the strictly binary tree. The executable should construct the corresponding strictly binary tree and output to `out_file1` a post-order traversal of the strictly binary tree. The output files `out_file2` and `out_file3` store the "packing" of these rectangular implementation, with `out_file2` storing the dimensions of the rectangular rooms containing the rectangular blocks and `out_file3` storing the coordinates of the rectangular blocks.

The `main` function should return `EXIT_SUCCESS` when the correct number of arguments are provided, a strictly binary tree can be built successfully from the given input file, and all output files can be produced; otherwise, the `main` function should return `EXIT_FAILURE`.

2.1 Format of input file

`argv[1] in_file` contains the name of the file that stores the strictly binary tree representation of a "packing" of rectangular blocks. The file is divided into lines, and each line corresponds to a node in the strictly binary tree.

If it is a leaf node, which is a rectangular block, it has been printed with the format

```
"%d(%d,%d)\n",
```

where the first `int` (specified by `%d`) is the label of the rectangular block, followed by the dimensions (width, height) of the rectangular block, with the second `int` in the line being the width of the rectangular block and the third `int` in the line being the height. Except for the newline character, there are no white-space characters in the line. If there are n rectangular blocks in the "packing," the labels are from 1 through n.

If it is a non-leaf node, it is simply a character (followed by a newline character). The character is either `'V'` or `'H'`, representing either a vertical cutline or a horizontal cutline, respectively.

These nodes are printed in a pre-order traversal of the strictly binary tree. Except for the newline character, there are no other white-space characters in each line. For the example of three rectangular blocks, the input file is in `3.pr` as follows:

```
H
3(3,3)
V
1(5,4)
2(7,7)
```

The format with which we use to print the dimensions of a block to an input file should suggest to you that the width and height of a block could be stored as an `int`.

2.2 Format of first output file

`argv[2] out_file1` contains the name of the file that `pa2` would use to store the strictly binary tree in a post-order traversal fashion. The format of this file should be similar to that of the input file except the order in which you print the nodes. The file is divided into lines, and each line corresponds to a node in the strictly binary tree.

If it is a leaf node, which is a rectangular block, it should be printed with the format

`"%d(%d,%d)\n",`

where the first `int` is the label of the rectangular block, the second `int` is the width of the rectangular block and the third `int` is the height of the rectangular block.

If it is a non-leaf node, it is simply a character (followed by a newline character). The character is either `'V'` or `'H'`, representing either a vertical cutline or a horizontal cutline, respectively.

Except for the newline character, there are no other white-space characters in each line. For the example of three rectangular blocks, the first output file is in `3.po` as follows:

```
3(3,3)
1(5,4)
2(7,7)
V
H
```

2.3 Format of second output file

`argv[3] out_file2` contains the name of the file that `pa2` would use to store the dimensions of all rectangular blocks (leaf nodes) and smallest rectangular rooms (non-leaf nodes or internal nodes) of a "packing." As in the first output file, the nodes are printed in a post-order traversal of the strictly binary tree.

As before, if it is a leaf node, which is a rectangular block, it should be printed with the format

`"%d(%d,%d)\n",`

where the first `int` is the label of the rectangular block, the second `int` is the width of the rectangular block and the third `int` is the height of the rectangular block.

If it is a non-leaf node, it should be printed with the format

`"%c(%d,%d)\n",`

where the `char` is either `'V'` or `'H'`, representing either a vertical cutline or a horizontal cutline, respectively. The first and second `int`'s are the width and height, respectively, of the smallest rectangular room to enclose all rectangular blocks in the subtree whose root is the non-leaf node.

Except for the newline character, there are no other white-space characters in each line. For the example of three rectangular blocks, the second output file is in `3.dim` as follows:

```
3(3,3)
1(5,4)
```

```
2(7,7)
V(12,7)
H(12,10)
```

The format with which we use to print the dimensions of a smallest rectangular room to the output file should suggest to you that the width and height of a smallest rectangular room could be stored as an `int`.

2.4 Format of third output file

`argv[4]` `out_file4` contains the name of the file that `pa2` would use to store the coordinates of all rectangular blocks (leaf nodes) of a "packing."

The file should contain a line for each rectangular block. The ordering of the blocks in the output file should be the same as the ordering of blocks in the input file. Every line is of the format

`"%d((%d,%d)(%d,%d))\n"`,

where the first `int` specifies the label of the rectangular block. The first `(%d,%d)` corresponds to the dimensions (width, height) of the rectangular block. The second `(%d,%d)` corresponds to the x- and y-coordinates of the bottom left corner of the rectangular block in the "packing."

Except for the newline character, there are no other white-space characters in each line. For example, 3.pck stores this output as follows:

```
3((3,3)(0,7))
1((5,4)(0,0))
2((7,7)(5,0))
```

3 Submission

The assignment requires the submission (through Brightspace) of a zip file called `pa2.zip` that contains the source code (`.c` and `.h` files). You could create `pa2.zip` as follows:

```
zip pa2.zip *.c *.h
```

Your zip file should not contain a folder. You may also include a `Makefile` in the zip file. In that case, you can create `pa2.zip` as follows:

```
zip pa2.zip *.c *.h Makefile
```

4 Grading

This assignment has a base score of 100 points. It also gives you an opportunity to earn 50 bonus points. Since the PAs accounts for 45 points of the overall grade, the bonus points are equivalent to 4.5 points of the overall grade.

4.1 Base score of 100 points

The grade depends on the correctness of your program and the efficiency of your program. The first output file accounts for 30 points, and the second output file accounts for 30 points, and the third output file accounts for 40 points of the entire grade. Any output files that do not follow the formats specified in this assignment will be considered to be wrong.

It is important that your program can accept any legitimate filenames as input or output files. Even if you cannot produce all output files correctly, you should still write the `main` function such that it produces as many correct output files as possible. If you do not have a working algorithm to generate the necessary information of an output file, you should leave the output file as an empty file.

Up to 5 points will be deducted if your `main` function does not return the correct value.

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. Any memory issues (memory leaks or memory errors reported by `valgrind`) will result in 50% penalty.

Be aware that we set a time-limit for each test case based on the size of the test case. If your program does not complete its execution before the time limit for a test case, it is deemed to have failed the test case.

4.2 Bonus score of 50 points

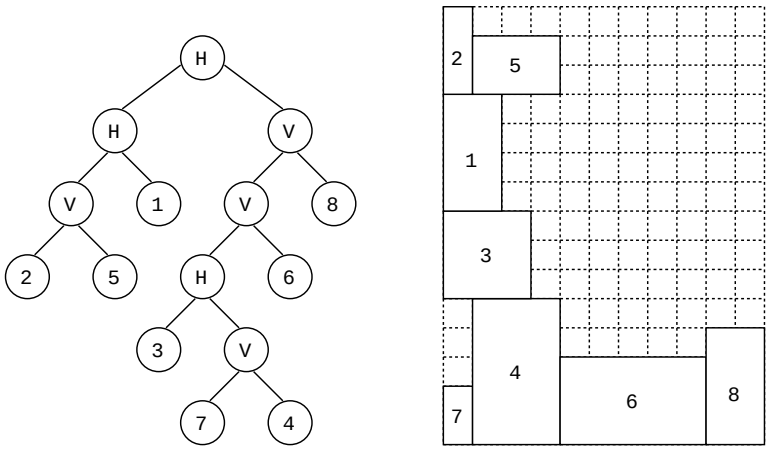
For the base score of 100 points, we will use test cases that are designed mainly to evaluate the time-complexity of your submission. For the bonus score of 50 points, we will use a different set of test cases that are designed to cause a recursive implementation to run into the stack overflow problem. To earn the bonus points, your submission must demonstrate its ability to handle such test cases while still satisfying the time-complexity requirement. (A recursive implementation may also run into the stack overflow problem for some test cases used for the time-complexity evaluation if a recursive function in the implementation requires a large stack frame.)

Note that we are not asking you to have two different approaches to handle these two sets of test cases. You should have a single approach that can handle these two sets of test cases satisfactorily, i.e., it satisfies the time-complexity requirement and it avoids the stack overflow problem.

5 What you are given

We provide two sample input files (`3.pr` and `8.pr`) for you. The corresponding first, second, and third output files for `3.pr` are `3.po`, `3.dim`, and `3.pck`, and those for `8.pr` are `8.po`, `8.dim`, `8.pck`. The figure in the next page shows the topology and "packing" of the 8-block example.

Three more input files are provided (`100.pr`, `500.pr`, `1K.pr`). However, we do not provide you the corresponding output files.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