Homework 6_1 [heapsort.cpp]

Variable analysis

Heap

1)

HeapType	
type	**name**
Element [MAX_ELEMENT]	heap
int	heap_ size

heap : heap represented in array

heap_ size : size of heap

2) element : Elements used in the heap

element	
type	**name**
int	key

key : the criteria for heap

Function analysis

1) void build_max_heap(HeapType *h)

: The purpose of this function is build max heap. We can build a max heap in a bottom-up manner by moving the element to meet the heap property. For the array of length N, all elements in N/2+1 ...N already meet heap property.(no child node) So we don't need to check N/2+1 ~ N th node meet heap property. Thus, walk backwards through the array from n/2 to 1 , moving the element on each node until it meets the heap property. The order of bottom-up processing guarantees that the children of node i are heaps when i is processed.

The basic principles are as belows.

while decreasing the index from heap_size/2 to 1, follow these processes.

Compare the value of the child node with the parent node.

Variable `child` indicates index that has larger key between left and right .

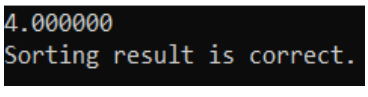
if parent >= child , it satisfys heap property and break the loop

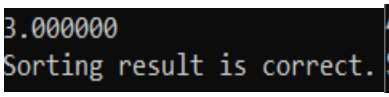
else (parent < child), it doesn't meet heap property. So parent =child and move down one level to find proper place. (we don't need to swap parent and child.).

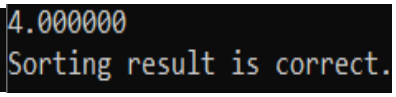
```
void build_max_heap(HeapType *h)
{
          int parent, child;
          element temp ;
          int i;

          for (int i = h->heap_size/2; i >= 1; i--) {

                    parent = i;
                    child = 2 * i; //left

                    temp = h->heap[parent]; // find proper place where temp can be inserted.
                    // The process of comparing with the parent node as it traverses the
tree
                    while (child <=h->heap_size ) {
                              if ((child + 1 <= h->heap_size) && (h->heap[child].key <= h-
>heap[child + 1].key)) // if right child exists and left < right
                                        child++; //renew child as index of right node.
                             if (temp.key >= h->heap[child].key) // parent >= child  -> meet
heap property                             break;

                             //if do not meet heap property
                             h->heap[parent] = h->heap[child]; // parent = child

                             // Move down one level
                             parent = child;
                             child = parent * 2;
                    }
                    h->heap[parent] = temp; // put temp in proper place
}
```

[result]

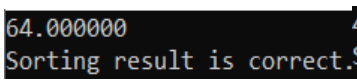
Input_size=10000

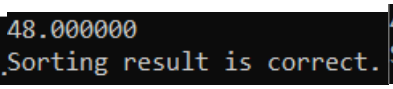


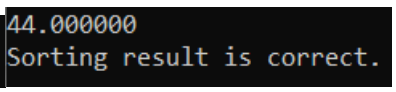




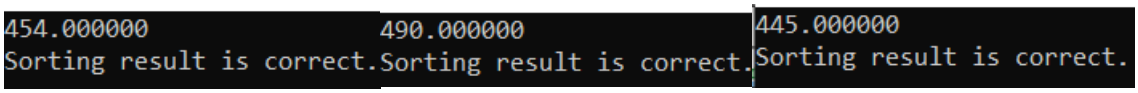
Input_size=100000



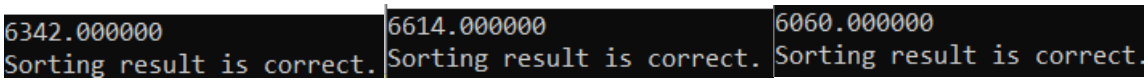




Input_size=1000000



Input_size=10000000



:as the input size increases, the time required increases linearly. So the time complexity of buld_max_heap is O(N) .

Homework 6_2 [Huffman.cpp]

Huffman code

- Algorithm used to efficiently compress data and belongs to the grid algorithm.

- Depending on the frequency of data, there is a process of taking out two small nodes from the priority queue and combining them to create a tree.

- There are two ways to express a fixed length code and a variable length code. And we use variable length code in this code.

Variable analysis

Heap

HeapType	
type	**name**
element [MAX_ELEMENT]	heap
int	heap_ size

heap : heap represented in array

heap_ size : size of heap

General

1) Input_huff : Input data for huffman code

Input_huff	
type	**name**
char *	data
int*	freq
Int	size

data : Character array (a ~ f)

freq : Frequency array

size: Number of characters

2) TreeNode : Structure for huffman binary tree

TreeNode	
type	**name**
char	data
int	key
int [MAX_BIT]	bit
int	bit_size
TreeNode*	l
TreeNode*	r

data : Character array (a ~ f)

freq : Frequency

bits : Huffman codeword

bit_size : Huffman codeword's size

l : Left child of huffman binary tree

r : Right child of huffman binary tree

3) Structure for bits stream

bits_stream	
type	**name**
int *	stream
int	length

Stream : encoded data

Length : length of encoded data

4) element : Elements used in the heap

element	
type	**name**
TreeNode *	ptree
int	key

ptree : the address of root

key : frequency of each character

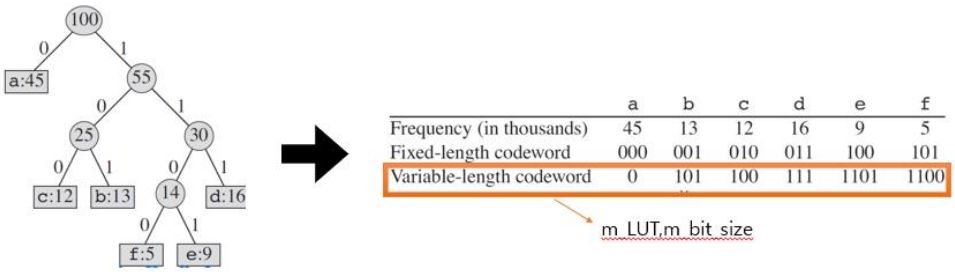
5) int ** m_LUT , *m_bit_size **:** save cord word for each character

6) m_char_size : the number of types of character used in data

Function analysis

1) void huffman_traversal(TreeNode *node)

: The purpose of this function is to make huffman cordword from given Huffman binary tree.



	a	b	c	d	e	f
Frequency (in thousands)	45	13	12	16	9	5
Fixed-length codeword	000	001	010	011	100	101
Variable-length codeword	0	101	100	111	1101	1100

m_LUT,m_bit_size

We have to travel all nodes in Huffman binary tree and find cordword for each character. For it, we can use variable 'bits[]' and bits_size in each Tree Node. It saves the codeword for each node. When it moves from parent to child, the child has same codeword except for just last 1 bits. So child copy parent's cordword and add just new bit depending on left or right child. If left, bit '0' will added and vice versa. These can be implemented by following below rules.

1. If Left child exists

   : inherit current node's codeword to left child. And add bit '0' to left child.

   Then recursive call with parameter left.

2. If Right child exists

   : inherit current node's codeword to right child. And add bit '1' to right child.

   Then recursive call with parameter right.

3. If No child exists

   : (=leaf node). The bits and bits_size saved in current TreeNode should be moved into m_LUT and m_bit_size. (because leafnode has character data). Depending on what character each node has, we have to save cordword at different index of m_LUT and m_bits_size. (because m_LUT and m_bit_size are ascending order) Thus we subtracts 'a'

to find out which index the current cordword should be stored in.

The implementation of this explaination is as below.

```
// Generate the huffman codeword from the huffman binary tree
// input: root node
// output: m_LUT, m_bit_size
void huffman_traversal(TreeNode *node)
{
	if (node == NULL)
		return;

	//left -> 0 ,right ->1
	if (node->l !=NULL) {

		//inherit the same codeword from parent
		for (int i = 0; i < node->bit_size;i++) {
			node->l->bits[i] = node->bits[i];
		}
		// add new  bit '0' to child node
		node->l->bits[node->bit_size] = 0;
		node->l->bit_size = node->bit_size + 1;
		huffman_traversal(node->l); //recursive call

	}
	if (node->r!=NULL) {

		//inherit the same codeword from parent
		for (int i = 0; i < node->bit_size; i++) {
			node->r->bits[i] = node->bits[i];
		}
		// add new bit '1' to child node
		node->r->bits[node->bit_size] = 1;
		node->r->bit_size = node->bit_size + 1;
		huffman_traversal(node->r);
	}
	//if leaf node. set m_LUT and m_bit_size.
	if ((node->r == NULL) && (node->l == NULL)) {
			int index = node->data - 'a'; //find index

			//copy cord word from TreeNode to m_LUT
			for (int i = 0; i < node->bit_size; i++) {
				printf("%d", node->bits[i]);
				m_LUT[index][i] = node->bits[i];
			}
			//copy also size of cordword.
			m_bit_size[index] = node->bit_size;
	}
}
```

: Finally, The cordword for each character will be saved into m_LUT by this function.

2) void huffman_encoding(char *str, bits_stream *bits_str)

```
// Return the total length of bits_stream
void huffman_encoding(char *str, bits_stream *bits_str)
{
	int interval=0; // from where to save encoded data

	for (int i = 0; i < strlen(str); i++) {
		int index = str[i] - 'a'; // find m_LUT's index of current char
		//copy codeword to stream per character
		for (int j = 0; j < m_bit_size[index]; j++) {

			bits_str->stream[interval+j] = m_LUT[index][j];
			bits_str->length++;
		}
		interval += m_bit_size[index]; //find next start index
	}

	printf("\n* Huffman encoding\n");
	printf("total length of bits stream: %d\n", interval);
	printf("bits stream: ");
	for (int i=0; i < interval; i++)
		printf("%d", bits_str->stream[i]);
	printf("\n");
}
```

: In this function, we encode the given str into bit_str using m_LUT and m_bit_size. Check the character sequentially and save each character's cordword to stream. The variable `interval` is used to know from which index of stream to save current character's cordword sequentially. So in every loop ,`interval` is added as long as the length of the cordword stored just before. After all loops, ,`interval` indicates the length of encoded data. The variable `index` tells you at which index of m_LUT the codeword corresponding to current character is stored.

3) int huffman_decoding(bits_stream *bits_str, TreeNode *node, char *decoded_str)

: In this function, we decode given bits_str using Huffman binary tree. In Huffman code, the prefix of one codeword cannot be another codeword and we can use this speciality in this function . It needs two process; the one is moving Treenode according to bit(0 or 1) and the other is to check if node has char data.

Step 1. if current pointing bit is '0' , move to left node. if current pointing bit is '1', move to right node

Step 2. if node has char data, add it to decoded_str.

```
int huffman_decoding(bits_stream *bits_str, TreeNode *node, char *decoded_str)
{
	int index_char = 0; // index of decoded str
	TreeNode* cur =node;
```

```
        for (int i = 0; i < bits_str->length; i++) {
                if (bits_str->stream[i] == 0)
                {
                        cur = cur->l; //move to left child
                }
                else {
                        cur = cur->r; // move to right child
                }

                if (cur->data != NULL) // if node has char data(= leaf node)
                {
                      decoded_str[index_char++] = cur->data; // add data to decoded_str
                        cur = node; // initialize to root for next decoding
                }
        }

        printf("\n* Huffman decoding\n");
        printf("total number of decoded chars: %d\n", index_char);
        printf("decoded chars: ");
        for (int i = 0; i < index_char; i++)
                printf("%c", decoded_str[i]);
        printf("\n");
        return index_char;
}
```

For example 0101100 with below Huffman binary tree can be decoded into a b c

index	Bit_stream	Step 1	Step 2
i=0	0	Move to left child	Char 'a' is added to decoded_str
i=1	1	Move to right child	Node has no char data
i=2	0	Move to left child	Node has no char data
i=3	1	Move to right child	Char 'b' is added to decoded_str
i=4	1	Move to right child	Node has no char data
i=5	0	Move to left child	Node has no char data
i=6	0	Move to left child	Char 'c' is added to decoded_str

[result]

1)input : abacdebaf

```
0100101111001101111* Huffman codeword
a: 0
b: 101
c: 100
d: 111
e: 1101
f: 1100

* input chars: abacdebaf

* Huffman encoding
total length of bits stream: 23
bits stream: 01010100111110110101100

* Huffman decoding
total number of decoded chars: 9
decoded chars: abacdebaf
```

2) input : ab

```
0100101111001101111* Huffman codeword
a: 0
b: 101
c: 100
d: 111
e: 1101
f: 1100

* input chars: ab

* Huffman encoding
total length of bits stream: 4
bits stream: 0101

* Huffman decoding
total number of decoded chars: 2
decoded chars: ab
```