Problem 1 (2 parts, 30 points) **Singly Linked Lists**

Consider a singly linked list that is implemented using the following `struct` definitions.

```
typedef struct llnode_t {
    int key;
    void* data;
    struct llnode_t* next;
}LLNode;

typedef struct {
    int size;
    LLNode* head;
} SLinkedList;
```

Part A (8 points) Assuming a **64-bit** system and proper memory alignment, consider the following function.

```
SLinkedList* create_slinkedlist(void) {
    SLinkedList* newList = (SLinkedList*)malloc(sizeof(SLinkedList));
    newList->head = NULL;
    newList->size = 0;
    return newList;
}
```

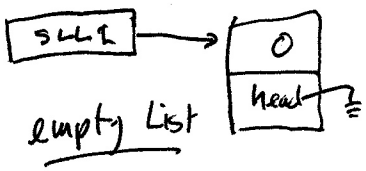
A.1 What integer is passed to `malloc` when this function executes? **16**.

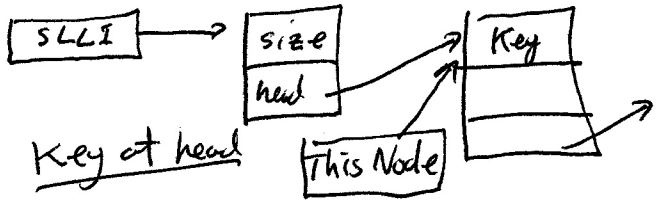
A.2 How much space is allocated for the locals in this function's activation frame? **8** **bytes.**

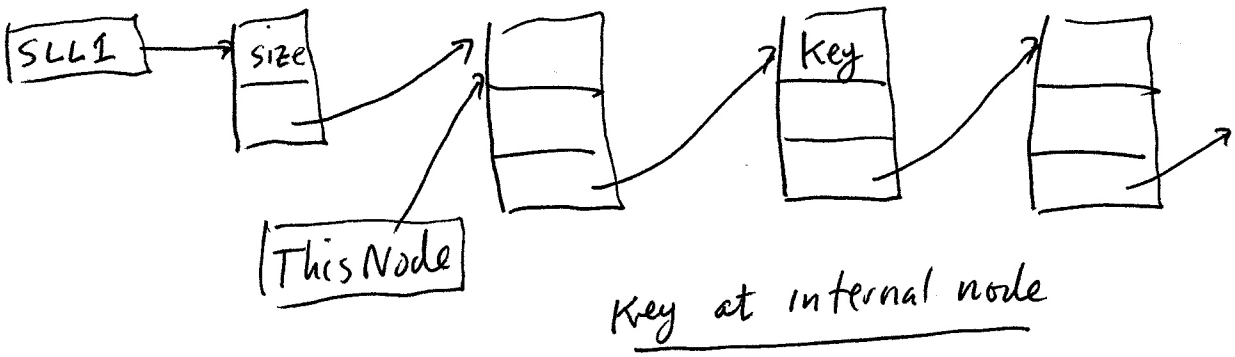
Part B (22 points) On the next page, complete the C function `FindAndSplit` that takes a pointer to a list `SLL1` and an integer `key`. It should find the `LLNode` with the matching `key`, if it exists. It should then split the list at the found node, returning a new list from that node to the end. If the key is not found, it should return an empty list. *Do not allocate additional nodes in this function.* Specifically, our function should:

1. Create a new list `SLL2`. `//already done`
2. Find the `LLNode` with the given `key`. Let's call the node N. Keep track of the number of nodes before node N.
3. Split `SLL1` at node N: `SLL2` holds the nodes from N to the end of list; SLL1 only holds nodes before N.
4. Update the size of `SLL1` and `SLL2`.
5. Return `SLL2`.

In the space below you might find it helpful to draw pictures of specific examples as you write the code.







```
SLinkedList *FindAndSplit(SLinkedList *SLL1, int key) {
     SlinkedList *SLL2 = create_slinkedlist();
     int count = 1;
     LLNode *ThisNode = SLL1->head; //trailing pointer

     if (!ThisNode) return SLL2; // SLL1 empty

     if (ThisNode->key == key){ //case: node at head matches
        SLL2->head = SLL1->head;
        SLL2->size = SLL1->size;
        SLL1->head = NULL;
        SLL1->size = 0;
        return SLL2;
     }

     while(ThisNode->next){ // walk the list
        if(ThisNode->next->key == key){ // split at ThisNode->next
           SLL2->head = ThisNode->next;
           SLL2->size = SLL1->size - count;
           SLL1->size = count;
           ThisNode->next = NULL;
           return SLL2;
        }
        ThisNode = ThisNode->next;
        count++;
     }
     return SLL2; // key not found
}
```

Problem 2 (5 parts, 35 points) **Heap Management**

Consider a memory allocator (malloc and free), such as described in class. Inside the C-code for the allocator, `unsigned *heapPtr` is the address of the next word that could be allocated in the heap, and `unsigned **freePtr` is the address of the first block (or object) on the free list (and the word at the address of each block on the free list is a pointer to the next block on the free list). The allocator uses a **best fit** strategy with a free list **sorted by increasing block address**, and never splits or coalesces blocks.

addr	value	addr	value	addr	value	addr	value	addr	value	addr	value
8000	4	**8032**	20	**8064**	4	**8096**	8048	**8128**	8	**8160**	45
8004	1234	**8036**	8016	**8068**	4	**8100**	8104	**8132**	8052	**8164**	0
8008	12	**8040**	4	**8072**	8088	**8104**	4	**8136**	4	**8168**	22
8012	8028	**8044**	12	**8076**	4	**8108**	2	**8140**	48	**8172**	7000
8016	4	**8048**	8	**8080**	8	**8112**	20	**8144**	4	**8176**	12
8020	8	**8052**	8072	**8084**	24	**8116**	8148	**8148**	0	**8180**	41
8024	12	**8056**	8	**8088**	8116	**8120**	4	**8152**	8	**8184**	40
8028	8052	**8060**	4	**8092**	16	**8124**	30	**8156**	0	**8188**	0

Suppose `heapPtr` = 8152 and `freePtr` = 8012. Consider each part below **independently**.

a) (5) How many **blocks and useable bytes** are on the free list? blocks = **_7___** bytes = **__84___**

b) (5) What value would be returned by the call **`malloc(13)`** **_____8116_____**

Which (if any) values in the above map would be changed by the call in (b)?

addr **8088** value **8148** addr_____ value_____ addr_____ value_____ No change (✓) _____
(fill in the address/value pairs above. There may be more pairs than needed.)

Fill in the values at this point: `heapPtr` = **8152** `freePtr`= **_8012__**

c) (5) What value would be returned by the call **`malloc(25)`** **____8156_____**

Which (if any) values in the above map would be changed by this call?

addr **_8152** value **_28_** addr_____ value_____ addr_____ value_____ No change (✓) _____

Fill in the values at this point: `heapPtr` = **_8184_** `freePtr`= **_8012_**

d) (5) Which (if any) values in the above map would be changed by the call **`free(8080)`**
addr **_8072_** value **_8080_** addr**_8080_** value**_8088_** addr_____ value___No change (✓)_____

Fill in the values at this point: `heapPtr` = **_8152_** `freePtr`= **_8012_**

e) Consider the following code, which may be called as a helper function during allocation or freeing blocks to reduce external fragmentation. Assume `freePtr` = 8012.

L1	`void merge(){`
L2	`  unsigned **current = freeptr;`
L3	`  unsigned **next;`
L4	`  unsigned cs, ns, xs;`
L5	`  while (*current) {  // find 2 blocks that can be coalesced`
L6	`    cs = *(current - 1);`
L7	`    next = current + 1 + cs/4;`
L8	`    if (*current == next) break;`
L9	`    current = *current;` `  }`
L10	`  if (*current) {  // coalesce them`
L11	`    ns = *(next - 1);`
L12	`    xs = cs + ns + 4;`
L13	`    *(current - 1) = xs;`
L14	`    *current = *next;` `  }`
L15	`  return;` `}`

e.1) (6 points) What are the values of the following at line **L10**?

current	8012	*current	8028	next	8028	cs	12

e.2) (4 points) What are the values of the following at **L13**?

ns	12	xs	28

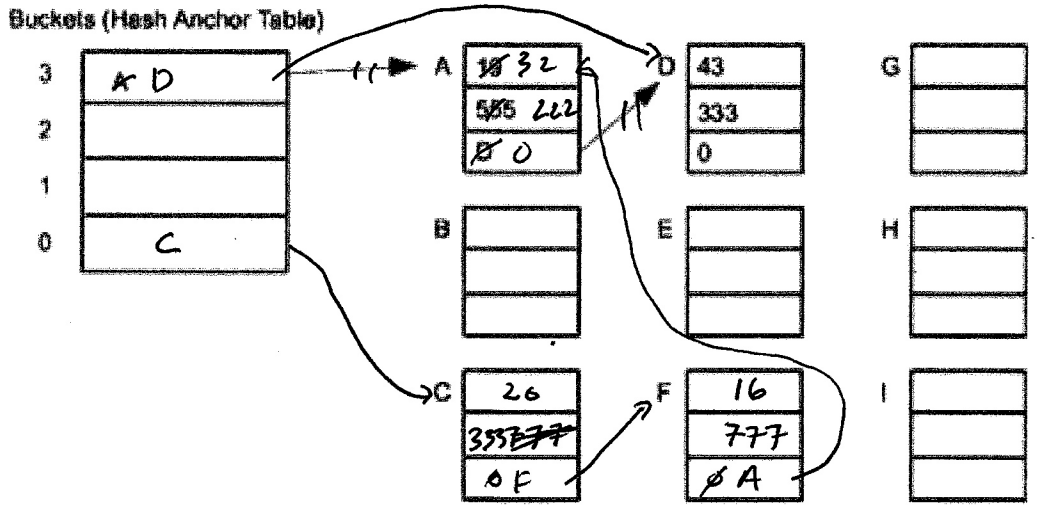
e.3) (5 points) Which (if any) values in the above map would be changed by lines **L13-L14**?

addr **_8008_** value **_28_** addr **_8012_** value **_8052_** addr_____ value___ No change (✓)_____

Problem 3 (2 parts, 35 points) **Hash Tables**

Part A (21 points) Consider an open hash table composed of a four-bucket table, with each bucket containing a variable length list. Each list entry has three slots <key, value, next> corresponding to the three word groupings in the entries section. The hash function is `key mod four`. Inserted entries are *appended to the end* of a bucket list. The initial state of the hash table is shown. List elements as allocated by malloc are shown in the figure. The symbol to the left of each list element (A, B, C,...) is the address returned by malloc. Entries that are freed are maintained in a last-in-first-out (LIFO) free list which starts out empty. *Be sure to reuse any blocks added to the free list before allocating unused blocks.*

Execute the access trace shown in the table below. For ease of representation, you may use the allocated blocks in any order. Show pointers both by their (symbolic) value, and with an arrow. If a value changes, cross it out and place the new value to the right. If a pointer changes, also place an x on the corresponding arrow, and draw the new arrow.



#	op	key	value	#	op	key	value
1	insert	20	777	4	delete	19	
2	insert	16	777	5	insert	32	222
3	insert	20	333				

Part B (14 points) Consider a *different* hash table that uses N **buckets**, each containing a singly linked list of L entries. That is the $N*L$ entries are uniformly distributed among the buckets. An application performs **1000** lookups of various keys: **600** of the lookups find the key in the hash table and **400** lookups fail to find the key and the average number of key comparisons is 7.3. A subsequent test performs **1000** lookups of various keys: **800** of the lookups find the key in the hash table and **200** lookups fail to find the key and the average number of key comparisons is 6.4 In both tests, the keys that are found are distributed throughout the buckets so that each position is equally likely to be where a key is found.

Unsorted lists require L key comparisons when the key is not found compared to (L+1)/2 when it is. Since the average comparisons decrease as the found fraction increases, we can infer that this implementation uses unsorted buckets. Thus, .3(L+1) + .4L = 7.3 or .7L = 7 giving L=10.

In this hash table the buckets are (bubble in your answer): ○ sorted ● not sorted

What is the value of L ? **10**