CSE320 System Fundamentals II

Dynamic Memory Allocation I

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Announcements

Exam I Postponed till 4/7 or 4/14

Exam I will cover through Dynamic Memory Allocation (today and Thursday)

Reading: Text 9.9-9.11

Dynamic Memory Allocation

Why dynamic memory allocation

- Suppose that you are writing a program that sorts as many words as users provide.
- How much memory should we prepare in advance when we are writing the program.
  - Max number of words * Max length of each word?
  - It can be a waste of space.
  - How much allocation is enough?

Dynamic Memory Allocation

Solution

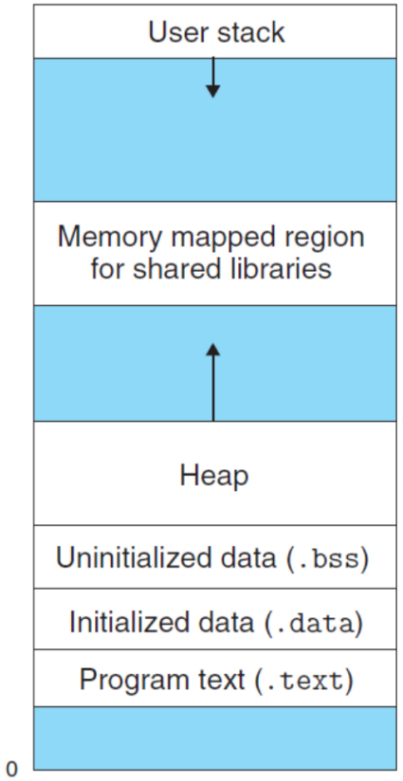
- Allocate memory as necessary
- Free memory when not using it

Declared in `stdlib.h`, are

- **`malloc`** that allocates a memory space in the heap area
- **`free`** that deallocates the memory

```
#include <stdlib.h>

void *malloc(size_t size);
void free(void *ptr);
```



Dynamic Memory Allocation

Additional C runtime memory allocation functions

- **calloc** that allocates a memory space in the heap area and initializes it to all zero values
- **realloc** increases the size of an allocated block.
  - If it can be done at the same block location, the returned address matches the pointer provided.
  - Otherwise, a new address is given for the allocated space and the contents are copied to the new area.

```
#include <stdlib.h>

void *calloc(size_t nmemb, size_t size);
void *realloc(void *ptr, size_t size);
```

Example 1: read words and sort them

```c
// sort.c
#include <stdio.h>
#include <string.h>
#include <stdlib.h>
void ReadWords(char ***pwords, int *pn) {
    int i, n;
    char **words;
    char word[100];

    printf("Number of words: ");
    scanf("%d", &n);

    words = (char**)malloc(n * sizeof(char*)); //dynamic mem allocation
    for(i = 0; i < n; i++) {
        printf("Word %d of %d: ", i+1, n);
        scanf("%99s", word);
        words[i] = strdup(word); //malloc + strcpy
    }
    *pwords = words; //unlike stack vars, heap memory outlives the function
    *pn = n;
}
```

```c
void Swap(char **p, char **q) {       //swap two strings pointers
    char *t;
    t = *p, *p = *q, *q = t;
}

void SortWords(char **words, int n) {
    int i, j;
    for(i = 0; i < n; i++)
        for(j = i + 1; j < n; j++)
            if(strcmp(words[i], words[j]) > 0)
                Swap(words+i, words+j);
}

void PrintWords(char **words, int n) {
    int i;
    printf("Words\n");
    for(i = 0; i < n; i++)
        printf("%2d: %s\n", i, words[i]);
}
```

```c
void FreeWords(char **words, int n) {
    int i;
    for(i = 0; i < n; i++)
        free(words[i]);     //free the mem alloc'd by strdup
    free(words);   //free the mem alloc'd by malloc
}

int main() {
    int n;
    char **words;

    ReadWords(&words, &n);
    PrintWords(words, n);
    SortWords(words, n);
    PrintWords(words, n);
    FreeWords(words, n);
}
```

Example 2: Linked List [list.h]

```
// list.h
#ifndef __LIST__
#define __LIST__
#define offsetof(st, m)         ((size_t) &(((st *)0)->m))
#define containerof(ptr, st, m) ((st *) (((char*)(ptr)) - offsetof(st, m)))
struct List {
    struct List *prev, *next;
};
void list_init_head(struct List *head);
int list_is_empty(struct List *head);
int list_size(struct List *head);
void list_add_to_prev(struct List *pos, struct List *list);
void list_add_to_next(struct List *pos, struct List *list);
struct List* list_remove(struct List *list);
void list_add_to_last(struct List *head, struct List *list);
void list_add_to_first(struct List *head, struct List *list);
struct List* list_remove_last(struct List *head);
struct List* list_remove_first(struct List *head);
struct List* list_find(struct List *head, void *data,
                       int (*comp)(struct List *list, void *data));
#endif
```

[list.c]

```c
// list.c
#include <stdio.h>
#include <stdlib.h>
#include "list.h"
void list_init_head(struct List *head) {
    head->next = head->prev = head;
}
int list_is_empty(struct List *head) {
    return head->next == head;
}
int list_size(struct List *head) {
    int count = 0;
    struct List *list;
    for(list = head->next; list != head; list = list->next)
        count++;
    return count;
}
```

[list.c]

```
void list_add_to_prev(struct List *pos, struct List *list) {
    list->next = pos;
    list->prev = pos->prev;
    pos->prev->next = list;
    pos->prev = list;
}
void list_add_to_next(struct List *pos, struct List *list) {
    list_add_to_prev(pos->next, list);
}
struct List* list_remove(struct List *list) {
    list->prev->next = list->next;
    list->next->prev = list->prev;
    list->next = list->prev = NULL;
    return list;
}
```

[list.c]

```
void list_add_to_last(struct List *head, struct List *list) {
    list_add_to_prev(head, list);
}
void list_add_to_first(struct List *head, struct List *list) {
    list_add_to_next(head, list);
}
struct List* list_remove_last(struct List *head) {
    return list_remove(head->prev);
}
struct List* list_remove_first(struct List *head) {
    return list_remove(head->next);
}
struct List* list_find(struct List *head, void *data,
                       int (*comp)(struct List *list, void *data)) {
    struct List *pos;
    for(pos = head->next; pos != head; pos = pos->next)
        if(comp(pos, data))
            return pos;
    return NULL;
}
```

[sort_list.c]

```c
//sort_list.c
#include <stdio.h>
#include <stdlib.h>
#include <string.h>
#include "list.h"
#define ORDERED_INSERT  0

typedef struct Person {
    char *name;
    long id;
    struct List list;
} Person;
```

[sort_list.c]

```
Person* NewPerson(char *name, long id) {
    Person *p = //TODO 1: allocate mem for p of size sizeof(Person)
    p->name = strdup(name);
    p->id = id;
    return p;
}

void FreePerson(Person *p) {
    //TODO 1: free p->name
    //TODO 1: free p
}

int CompareName(struct List *list, void *name) {
    return strcmp(  containerof(list, struct Person, list)->name,
                    (char*)name) > 0;
}
```

[sort_list.c]

```
void ReadNames(struct List *head) {
    long id = 0;
    printf("Enter names or q to stop.\n");
    while(1) {
        char name[100];
        scanf("%99s", name);
        if(strcmp(name, "q") == 0)
            break;

        Person *p = NewPerson(name, id++);
#if ORDERED_INSERT
        struct List *pos = list_find(head, name, CompareName);
        if(pos != NULL) //TODO 2:
        else            //TODO 2:
#else
        list_add_to_last(head, &p->list);
#endif
    }
}
```

[sort_list.c]

```
void Swap(char **p, char **q) {
    char *t;
    t = *p, *p = *q, *q = t;
}

void SortList(struct List *head) {
    struct List *i, *j;
    for(i = head->next; i != head; i = i->next) {
        char **name_i = &containerof(i, struct Person, list)->name;
        for(j = i->next; j != head; j = j->next) {
            char **name_j = &containerof(j, struct Person, list)->name;
            if(strcmp(*name_i, *name_j) > 0)
                Swap(name_i, name_j);
        }
    }
}
```

[sort_list.c]

```
void PrintList(struct List *head) {
    struct List *pos;
    printf("Person list:\n");
    for(pos = head->next; pos != head; pos = pos->next) {
        Person *person = containerof(pos, struct Person, list);
        printf("%2ld: %s\n", person->id, person->name);
    }
}

void FreeList(struct List *head) {
    while(!list_is_empty(head)) {
        struct List *pos = list_remove_first(head);
        Person *person = //TODO 1: get person from pos
        FreePerson(person);
    }
}
```

[sort_list.c]

```
int main() {
    struct List head;
    list_init_head(&head);

    ReadNames(&head);
    PrintList(&head);
#if ORDERED_INSERT == 0
    SortList(&head);
    PrintList(&head);
#endif
    FreeList(&head);

    return 0;
}
```

Common Memory Related Bugs

There are numerous mistakes even experienced programmers make when working with dynamic memory allocators.

- Dereferencing Bad Pointers
- Reading Uninitialized Memory
- Allowing Stack Buffer Overflows
- Assuming objects and pointers are the same size
- Off-by-One Errors
- Referencing a Pointer rather than the object it points to
- Misunderstanding Pointer Arithmetic
- Referencing Non-existant Variables
- Referencing Data in Free Heap Blocks
- Introducing Memory Leaks

Common Memory Related Bugs

- Dereferencing Bad Pointers

  Ex:

```
scanf("%d", val);   // shoulds be scanf("%d", &val);
```

- Reading Uninitialized Memory
- Allowing Stack Buffer Overflows

  Ex:

```
void bufoverflow() {
   char buf[64];

   gets(buf);  // gets() does not limit data
   return;
}
```

Common Memory Related Bugs

- Assuming objects and pointers are the same size

  Ex:

```
int **A = (int **)Malloc(n * sizeof(int));    // should be sizeof(int *)
```

- Off-by-One Errors

  Ex:

```
void makeArray2() {
    int **A = (int **)Malloc(n * sizeof(int *));
    for (I = 0; I <= n; i++) {     // use A
     …
}
```

- Referencing a Pointer rather than the object it points to

Ex:

```
int *binheapDelete(int **binheap, int *size) {

…

   *size--;      // !!! Should be (*size)--; The code changes the value of the pointer not the contents
```

Common Memory Related Bugs

- Misunderstanding Pointer Arithmetic

Ex:

```
int *search(int *p, int val) {
   while (*p && *p ~= val) {
      p += sizeof(int);   // Should be just p++;
}
```

- Referencing Non-existant variables

Ex:

```
int *stackref() {
   int val = 5;
    return &val;
}
```

Common Memory Related Bugs

- Referencing data in free heap blocks

Ex:

```
int *binheapDelete(int **binheap, int *size) {
…
   *size--;     // !!! Should be (*size)--; The code changes the value of the pointer not the contents
```

- Introducing Memory Leaks

Ex:

```
void leak(int n) {
   int *x = (int *)malloc(n*sizeof(int));
   return;  // x is never freed!
}
```

Questions?