CSE 333 – Section 2: Structs, Debugging, Memory Management, and Valgrind

Plenty of resources focused on GDB can be found at the CSE351 GDB page and the CSE333 Resource Page:
https://courses.cs.washington.edu/courses/cse351/21sp/gdb/ and
https://courses.cs.washington.edu/courses/cse333/21sp/resources.html

In this class, it is very helpful to be comfortable with gdb as a tool to debug C/C++ code. Note that gdb allows you to see the source code while you run it, and that it has many useful commands to analyze your program.

For GDB to work with your C program, compile it using the "-g" flag

Starting GDB

To start up gdb, run the following command. Note that the `-tui` flag is optional. It is used to enable a text UI.

```
bash$ gdb -tui <program file name>
```

Here is a list of some essential gdb commands, if you want to know more, ask a TA or investigate the resources at the top of the page.

[IN GDB] Controlling Program Execution

- run <command_line_args> Run the program with provided command_line_args
- next Go to next instruction, but don't five into functions
- step Go to next instruction, and dive into functions
- finish Continue until current function returns
- quit close gdb

[IN GDB] Examining the Current Program

- list Shows the current or given source context
- backtrace Shows the call stack
- up Moves up a stack frame
- down Moves down a stack frame
- print <expression> Prints content of variable/memory location/register

[IN GDB] Setting Breakpoints and Continuing

- break <where> Set a new breakpoint
- info breakpoints Prints information about the set breakpoints
- continue Continue normal execution

1. Debugging with gdb

Provided below is a segment of `reverse.c`. The program intends to take a string, and then reverse the ordering of the characters in the string. For example, if `"Hello"` is provided, then `"olleH"` should be returned.

gcc -Wall -std=c11 -g -o reverse reverse.c

Identify and fix the errors that are in `reverse.c`. Use gdb to analyze the program for errors.

```
#define MAX_STR 100   /* length of longest input string */

#include <stdio.h>
#include <stdlib.h>
#include <string.h>

/* Return a new string with the contents of s backwards */
char * reverse(char * s) {
  char * result = NULL;            /* the reversed string */
  int L, R;
  char ch;

  /* copy original string then reverse and return the copy */
  strcpy(result, s);

  L = 0;
  R = strlen(result);
  while (L < R) {
    ch = result[L];
    result[L] = result[R];
    result[R] = ch;
    L++; R--;
  }

  return result;
}
```

2. Leaky Code and Valgrind

```c
#include <stdio.h>
#include <stdlib.h>

/* Returns an array containing [n, n+1, ... , m-1, m]. If n>m, then the
   array returned is []. If an error occurs, NULL is returned. */
 int* rangeArray(int n, int m) {
  int length = m - n + 1;

  /* Heap allocate the array needed to return */
  int *array = (int*) malloc(sizeof(int) * length);

  /* Initialize the elements */
  for (int i = 0; i <= length; i++) {
     array[i] = i + n;
  }

  return array;
}

/* Accepts two integers as arguments */
int main(int argc, char *argv[]) {
  if (argc != 3) return EXIT_FAILURE;

  int n = atoi(argv[1]), m = atoi(argv[2]);  /* Parse cmd-line args */
  int *nums = rangeArray(n, m);

  /* Print the resulting array */
  for (int i = 0; i <= (m - n + 1); i++) {
    printf("%d", nums[i]);
  }

  /* Append newline char to our output */
  puts("");

  return EXIT_SUCCESS;
}
```

3. Structs and Pointers

To define a struct, we use the `struct` statement. A struct typically has a name (a tag), and one or more members. The `struct` statement defines a new type:

```
struct fruit_st {
  OrchardPtr origin;
  int volume;
};
```

The C Programming language provides the keyword `typedef`, which defines an alternate name for a type:

```
typedef struct fruit_st {
  OrchardPtr origin;
  int volume;
} Fruit;
```

The above defines the name `Fruit` to represent the type `struct fruit_st`.

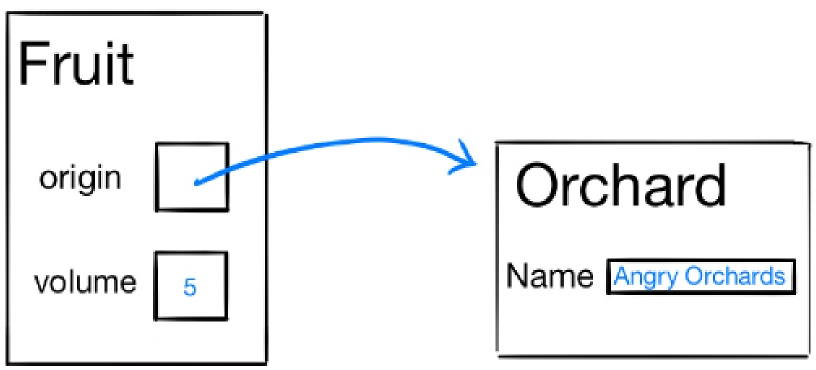
Now let's define the Orchard type used in Fruit:

```
typedef struct orchard_st {
  char name[20] ;
} Orchard, *OrchardPtr;
```

The above defines the name `Orchard` to represent the type `struct orchard_st` as well as the name `OrchardPtr` to represent a `struct Orchard*` (a pointer to a `struct orchard_st`)

Assume we've initialized a Fruit and corresponding Orchard with 'random' values.

Then we can draw a memory diagram for the above structs like so:

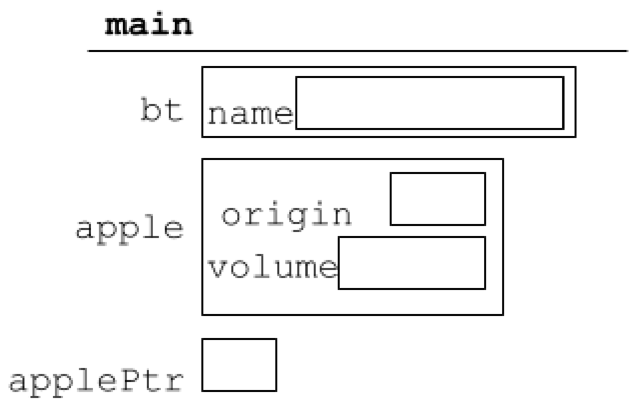


A `struct` is passed and returned by value. That means that **if we pass a struct as an argument, the callee function gets a local copy of the entire struct.** We will explore this in more detail in question 3.

What does the following program output?
Use the definitions of `Fruit` and `Orchard` from the first page of the section handout.

```
#include <string.h>
#include <stdio.h>
#include <stdlib.h>

int eatFruit(Fruit fruit) {
  fruit.volume -= 10;
  strcpy(fruit.origin->name, "Eaten Fruit Orchard");
  return fruit.volume;
}

void growFruit(Fruit* fruitPtr) {
  fruitPtr->volume += 7;
}

void exchangeFruit(Fruit** fruitPtrPtr) {
  Fruit *banana = (Fruit*)malloc(sizeof(Fruit));
  banana->volume = 12;
  banana->origin = (OrchardPtr)malloc(sizeof(Orchard));
  strcpy(banana->origin->name, "Banana Orchard");
  *fruitPtrPtr = banana;
}

int main(int argc, char* argv[]) {
  Orchard bt;
  strcpy(bt.name, "Apple Orchard");

  Fruit apple;
  Fruit* applePtr = &apple;
  apple.origin = &bt;
  apple.volume = 33;
  applePtr->volume = apple.volume;

  printf("1. %d, %s \n", applePtr->volume, applePtr->origin->name);
  apple.volume = eatFruit(apple);
  printf("2. %d, %s \n", applePtr->volume, applePtr->origin->name);
  growFruit(applePtr);
  printf("3. %d, %s \n", applePtr->volume, applePtr->origin->name);
  exchangeFruit(&applePtr);
  printf("4. %d, %s \n", applePtr->volume, applePtr->origin->name);

  free(applePtr->origin);
  free(applePtr);

  return 0;
}
```

(a) Draw a memory diagram for the program. We've put some boxes for the variables in `main()` to help get you started.



(b) What does this program output?

1. __________________, __________________

2. __________________, __________________

3. __________________, __________________

4. __________________, __________________

4. Reverse a Linked List [Extra Practice]

A node in a linked list is defined as follows:

```
struct Node {
  int value;
  struct Node* next;
};
```

Complete the function `reverse` to reverse the linked list and return the head of the resulting list.

Do not create new list nodes and do not modify the contents of a list node.
Assume `next == NULL` implies the end of the list.

```
struct Node* reverse(struct Node* head) {

}
```

5. Sorted Array To Binary Search Tree [Extra Practice]

A node in a tree is defined as follows:

```
struct TreeNode {
  int value;
  struct TreeNode* left;
  struct TreeNode* right;
};
```

Complete the implementation of the `sortedArrayToBST` function to convert a sorted integer array into a balanced binary search tree. The client to this method will invoke it as follows:

```
struct TreeNode* root = sortedArrayToBST(sortedArray, 0, n - 1);
```

where `sortedArray` is a sorted array of integers and `n` is the length of `sortedArray`.

```
struct TreeNode* sortedArrayToBST(int[] arr, int low, int high) {









}
```