CS61 Section Notes 4

(Week of 10/8 - 10/12)

Topics to be covered:
1. Code
2. Questions
4. Exceptions

Topics to be covered:

- **Arrays**
- **Structs**
- **Buffer overflow**

1. Code

A terrible programmer wrote the following code. It is designed to generate information about students and fill that information into a data structure. Two of the students, however, are celebrities, and therefore their information is sensitive. To generate their data, a password must be provided.

```
1 #include <stdio.h>
2 #include <string.h>
3
4 struct student_t {
5     char name[3][7];
6     int age;
7     char grade;
8 };
9
10 struct student_t global_pair[2];
11
12 void generate_students(struct student_t *students[3]) {
13    struct student_t sally = {
14          {"Sally","Henthorn","Ro"},
15         15,
16          'B'
17    };
```

```
18    struct student_t psyche = {
19         {"Psyche","Lazy","Murphy"},
20         2,
21         'A'
22    };
23    struct student_t harvey = {
24         {"Harvey","Dexter","Glenn"},
25         2,
26         'A'
27    };
28
29    students[0] = &psyche;
30    students[1] = &harvey;
31    students[2] = &sally;
32    students += 1;
33
34    printf("%s %s %s\n", sally.name[0],
sally.name[1],sally.name[2]);
35 }
36 void generate_secret_students(struct student_t *students[2],
 37                               char *password) {
38    struct student_t secret_1 = {
39         {"Secret","Oscar","Meyer"},
40         15,
41         'C'
42    };
43    struct student_t secret_2 = {
44         {"Secret","Betty","Crock"},
45         16,
46         'A'
47    };
48    char buffer[9];
49
50    strcpy(buffer, password);
51    if (!strcmp(buffer, "secure")) {
52         students[0] = &secret_1;
53         students[1] = &secret_2;
54    }
55 }
56

57 int main() {
58    struct student_t *students[3];
59    struct student_t *secret_students[2];
60    int sneaky_length = 9+sizeof(struct student_t)*2+4+4+1;
61    char sneaky[sneaky_length];
62
63    sneaky[sneaky_length-5] = 0xef;
64    sneaky[sneaky_length-4] = 0xbe;
65    sneaky[sneaky_length-3] = 0xad;
66    sneaky[sneaky_length-2] = 0xde;
67    sneaky[sneaky_length-1] = 0x0;
```

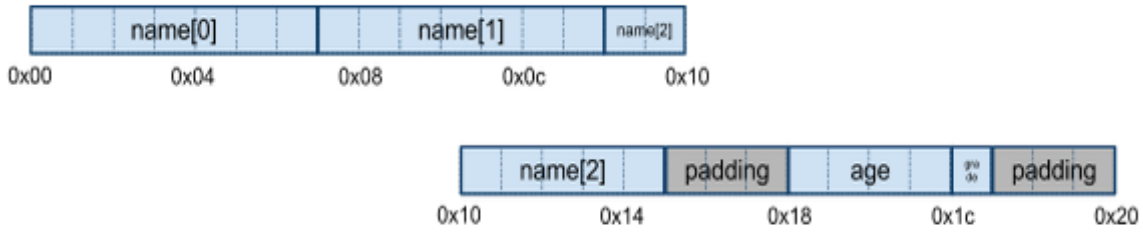
```
68
69    generate_students(students);
70    generate_secret_students(secret_students, sneaky);
71
72    printf("First student name: %s %s %s\n",
73          students[0]->name[0],
74          students[0]->name[1],
75          students[0]->name[2]);
76
77    return 0;
78 }
```

2. Questions

Assume this program is compiled for Linux using gcc running on an x86 processor.

Q1: What is the layout of a `struct student_t` in memory?

The following diagram shows the layout of a struct student_t. Hex numbers indicate the offset from the beginning of the struct. The struct is represented using 32 contiguous bytes. For reasons of space, we draw this over two lines.
Note that the field age is aligned at a multiple of four bytes from the beginning of the struct, and that padding is added at the end of the struct to make the total size a multiple of 4. These two facts ensure that in an array of struct student_t, the age fields are always placed at a memory address that is divisible by 4, as per the Linux/x86 alignment requirements.



Q2: If `global_pair` points to memory location 0x80049110, what memory location do each of the following refer to?

a. global_pair[0].name
b. global_pair[0].name[0]
c. global_pair[0].name[1]
d. &(global_pair[0].grade)
e. &(global_pair[1].grade)

a. 0x80049110 + 0x0 = 0x80049110
b. 0x80049110 + 0x0 = 0x80049110
c. 0x80049110 + 0x7 = 0x80049117
d. 0x80049110 + 0x1c = 0x8004912c

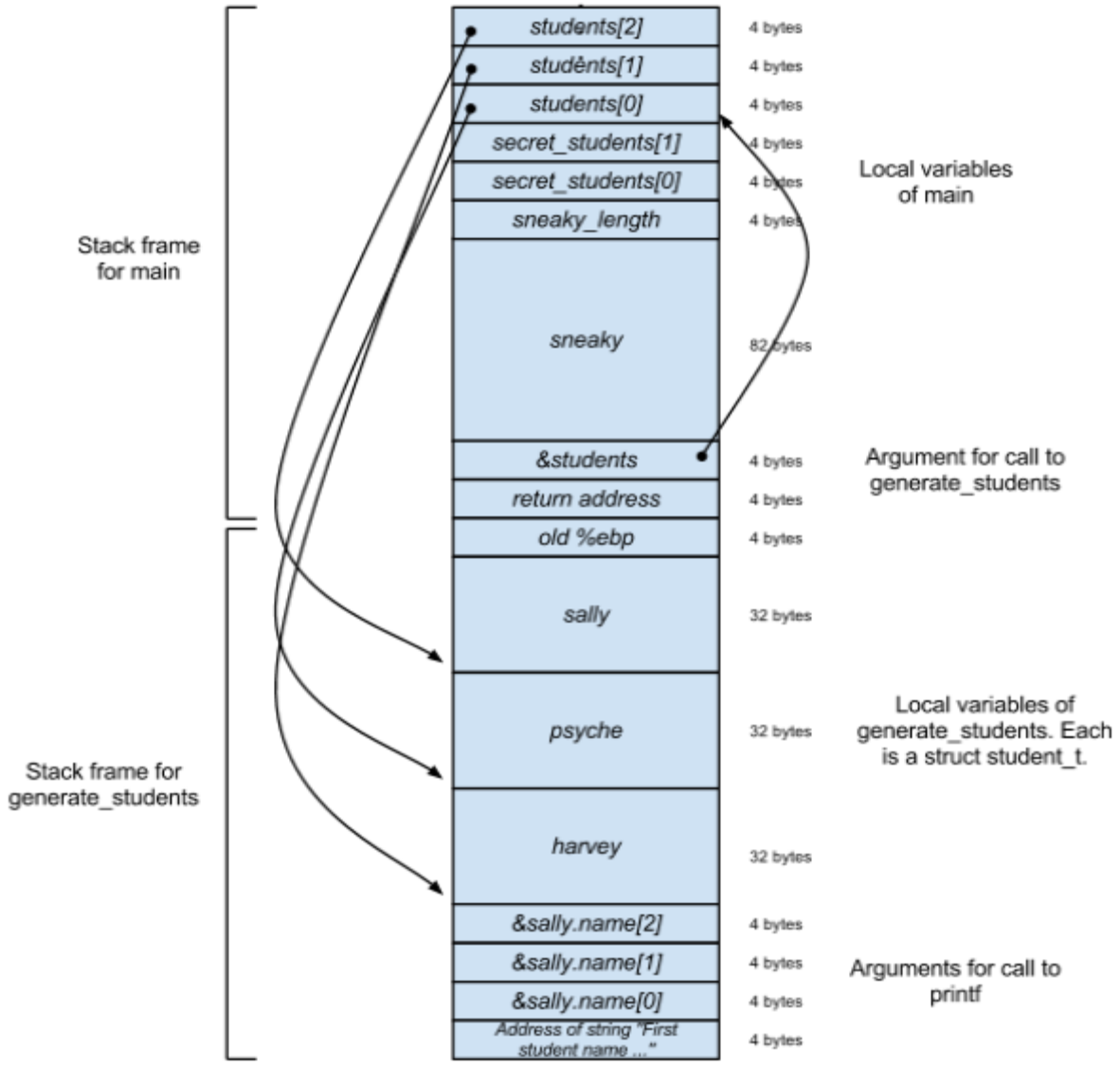
e. 0x80049110 + 0x20 + 0x1c = 0x8004914c

Q3: What will line 34 print and why?

"Sally HenthorRo Ro" because "Henthorn" plus the null terminating character at the end is 9 characters. Thus, only the first 7 characters will fit in the name[1] field. "Ro" will overwrite the last two characters of "Henthorn", and when the system attempts to print the name[1] field, the first null terminating character it encounters is after "Ro," so it prints the first 7 characters of "Henthorn" followed by "Ro."

Q4: What does the stack look like at the end of the generate_students() function?

The following diagram shows the state of the stack at the end of the function generate_students, that is, just after the return from printf. We assume that the function main does not push any caller-save registers on to the stack, and that generate_students does not push any callee-save registers on to the stack. We do not show the stack above the local storage for main, or below the stack from for generate_students. (What will the memory addresses below the stack frame for generate_students contain?) We also assume that the compiler is being fairly dumb about optimizing the code. For example, since the value of the variable sneaky_length is constant, a compiler might replace all uses of the variable with its constant value (82), and thus not need to compute the value of sneaky_length at runtime, nor store it on the stack.
The diagram is not drawn to scale, but the size of each element on the stack is indicated on the right of the diagram.
The arrows indicate what locations point to what other location. For example, in the location students[0] is the address of the struct student_t psyche. Similarly, students[1] contains the address of harvey, and the argument of the call to generate_students is the address of the array students (which is equal to the address of the first element of the array, students[0]). (Due to lack of space in the diagram, we do not show arrows from the arguments of the call to printf into the struct student_t sally.)



Q5: What is the overall structure of the data pointed to by the argument “students” at the end of the generate_students() function?

See answer for #4

Q6:What is the overall structure of the data pointed to by the “students” array declared in main()?

See answer for #4

Q7:Suppose (just for this question) that the function main was defined as follows.

```
100  int main() {
```

```
101     struct student_t *students[3];
102     struct student_t *secret_students[2];
103
104     generate_students(students);
105     generate_secret_students(secret_students, "wrongpwd");
106
107     printf("First student name: %s %s %s\n",
108         students[0]->name[0],
109         students[0]->name[1],
110         students[0]->name[2]);
111
112     return 0;
113  }
```

What will line 107 print and why?

Technically, we don't actually know what it will print. It depends on what printf() allocates on the stack. Most likely, it will print "Secret Betty Crock".
The pointers inserted into "students" pointed to the stack frame for generate_students(). When generate_students() returns, the stack frame is de-allocated.

When generate_secret_students() is called, its stack frame starts at the same place the stack frame generate_students() used to start.

Thus, where generate_students() allocated the struct on the stack for sally, generate_secret_students() allocates a struct for oscar meyer.

Then, where generate_students() allocated the struct for psyche, generate_secret_students() allocates space for the betty crock struct. Since the first pointer in students has been set to point to the space where psyche's struct resided, and the betty crock struct is now located there, students[0] dereferences to the betty crock struct, and thus "Secret Betty Crock" is printed.

Note that when printf() is called, the stack frame for generate_secret_students() has already been deallocated as well, so technically this memory access is invalid.

Q8: What are lines 60 through 67 doing?

Lines 60-67 are crafting a buffer overflow attack on generate_secret_students(). They are attempting to craft a buffer such that, when generate_secret_students() is called, the return address will be overwritten with 0xdeadbeef.

Q9: Why is sneaky_length the size that it is?

In order to reach the location of the return address in the previous stack frame, the buffer must skip over: the 9 byte character buffer and the two struct student_t's allocated at the beginning of the function, the return stack frame pointer (4 bytes), the return address itself (4 bytes), and space for a final null terminating character to make sure the strcpy() returns.

3. More Assembly + Homework tips

The following code has some very familiar behavior. Try to work through print and figure out what it is doing. Hint: Try to figure out what data structure is being used.

```
0804849e <print>:
        // Print out the global linked list
        void
        print(void)
 804849e:       55                      push   %ebp
 804849f:       89 e5                   mov    %esp,%ebp
 80484a1:       53                      push   %ebx
 80484a2:       83 ec 14                sub    $0x14,%esp
        struct int_list *head = ints;
 80484a5:       8b 1d 24 a0 04 08       mov    0x804a024,%ebx

        while (head != NULL) {
 80484ab:       85 db                   test   %ebx,%ebx
 80484ad:       74 19                   je     80484c8 <print+0x2a>
        printf("%d\n", head->num);
 80484af:       8b 03                   mov    (%ebx),%eax
 80484b1:       89 44 24 04             mov    %eax,0x4(%esp)
 80484b5:       c7 04 24 00 86 04 08    movl   $0x8048600,(%esp)
 80484bc:       e8 7f fe ff ff          call   8048340 <printf@plt>
        head = head->next;
 80484c1:       8b 5b 04                mov    0x4(%ebx),%ebx
        void
        print(void)
        {
                struct int_list *head = ints;
                while (head != NULL) {
 80484c4:       85 db                   test   %ebx,%ebx
 80484c6:       75 e7                   jne    80484af <print+0x11>
                printf("%d\n", head->num);
                head = head->next;
                }
        }
 80484c8:       83 c4 14                add    $0x14,%esp
 80484cb:       5b                      pop    %ebx
 80484cc:       5d                      pop    %ebp
 80484cd:       c3                      ret
```

Q10: What does this function do?
It prints the values of a linked list. The above is annotated with the corresponding lines of c code.

Magic is a slightly more complicated function, but is working on the same data structure.

```
// Insert a number into the global linked list
void
magic(int number)
{
```

```
8048444:       55                  push   %ebp
8048445:       89 e5                       mov    %esp,%ebp
8048447:       56                  push   %esi
8048448:       53                  push   %ebx
8048449:       83 ec 10                    sub    $0x10,%esp
804844c:       8b 75 08                    mov    0x8(%ebp),%esi
 struct int_list *head = ints;
804844f:       8b 1d 24 a0 04 08           mov    0x804a024,%ebx
 struct int_list *node = calloc(1, sizeof(*node));
8048455:       c7 44 24 04 08 00 00  movl   $0x8,0x4(%esp)
804845c:       00
804845d:       c7 04 24 01 00 00 00  movl   $0x1,(%esp)
8048464:       e8 17 ff ff ff              call   8048380 <calloc@plt>
 node->num = number;
8048469:       89 30                       mov    %esi,(%eax)

 // Zero elements in the list, so place ourselves first
 if (ints == NULL) {
804846b:       85 db                       test   %ebx,%ebx
804846d:       75 07                       jne    8048476 <magic+0x32>
   ints = node;
804846f:       a3 24 a0 04 08              mov    %eax,0x804a024
   return;
8048474:       eb 21                       jmp    8048497 <magic+0x53>
 }

 // We're smaller than the first element
 if (number < ints->num) {
8048476:       3b 33                       cmp    (%ebx),%esi
8048478:       7d 0c                       jge    8048486 <magic+0x42>
   node->next = ints;
804847a:       89 58 04                    mov    %ebx,0x4(%eax)
   ints = node;
804847d:       a3 24 a0 04 08              mov    %eax,0x804a024
   return;
8048482:       eb 13                       jmp    8048497 <magic+0x53>
 }

 // Loop until our value is between the next and the next-next element
 while (head->next != NULL && head->next->num < number) {
8048484:       89 d3                       mov    %edx,%ebx
8048486:       8b 53 04                    mov    0x4(%ebx),%edx
8048489:       85 d2                       test   %edx,%edx
804848b:       74 04                       je     8048491 <magic+0x4d>
804848d:       3b 32                       cmp    (%edx),%esi
804848f:       7f f3               jg     8048484 <magic+0x40>
   head = head->next;
 }

 // Insert ourselves between them
 node->next = head->next;
```

```
 8048491:      89 50 04                mov    %edx,0x4(%eax)
  head->next = node;
 8048494:      89 43 04                mov    %eax,0x4(%ebx)
}
 8048497:      83 c4 10                add    $0x10,%esp
 804849a:      5b              pop    %ebx
 804849b:      5e              pop    %esi
 804849c:      5d              pop    %ebp
 804849d:      c3              ret
```

Q11: What is this code doing?
This is the insert function for a sorted linked list. Walk through it in GDB with the students. The above version is annotated with what each bit of assembly is doing.

4. Exceptions

Exceptions are changes in control flow that are due to a change in the processors state. Exception handlers are run in **kernal mode** as opposed to regular code which is run in **user mode**. This gives them access to the kernel's stack and data. There are several types of exceptions:

Type of Exception	Cause of Exception	Return behavior	Example
Interrupt	Signal from I/O device	Returns to the next instruction	When the hard drive has finished fetching data, and is ready to return it
Trap	Intentional exceptions that occur during normal program flow	Returns to the next instruction	System Calls: e.g. fork, file i/o
Fault	Error conditions it is possible to recover from	Might return to the next instruction	Page faults, Divide by Zero errors, Seg faults
Abort	Error conditions it is not possible to recover from	Never returns to the program	Fatal hardware errors such as bit corruption

Exceptions are incredibly important as they are the way that your program can interact with the rest of the computer. It is necessary to understand how many of these exceptions work, to understand bugs that may occur and how to avoid them. (See example program)