CSE 351 Section 5 – Arrays and Buffer Overflow

Welcome back to section, we're happy that you're here ☺

Arrays

- Arrays are contiguously allocated chunks of memory large enough to hold the specified number of elements of the size of the datatype. Separate array allocations are not guaranteed to be contiguous.
- 2-dimensional arrays are allocated in row-major ordering in C (i.e. the first row is contiguous at the start of the array, followed by the second row, etc.).
- 2-level arrays are formed by creating an array of pointers to other arrays (i.e. the second level).

We have a two-dimensional matrix of integer data of size M rows and N columns. We are considering 2 different representation schemes:

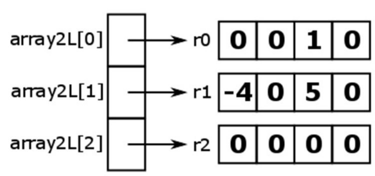
1) 2-dimensional array **`int`** `array2D[][]` // M*N array of ints
2) 2-level array **`int*`** `array2L[]` // M array of int arrays

Consider the case where $M = 3$ and $N = 4$. The declarations are given below:

2-dimensional array:	**2-level array:**
`int` `array2D[3][4];`	**`int`** `r0[4], r1[4], r2[4];` **`int*`** `array2L[] = {r0,r1,r2};`

For example, the diagrams below correspond to the matrix $\begin{bmatrix} 0 & 0 & 1 & 0 \\ -4 & 0 & 5 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$ for `array2D` and `array2L`:

0	0	1	0	-4	0	5	0	0	0	0	0
[0][0]	[0][1]	[0][2]	[0][3]	[1][0]	[1][1]	[1][2]	[1][3]	[2][0]	[2][1]	[2][2]	[2][3]



Fill in the following comparison chart:

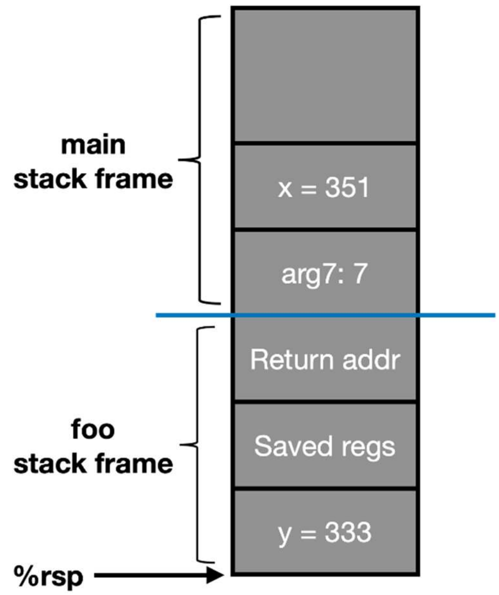
	2-dim array	2-level array
Overall Memory Used		
Largest *guaranteed* continuous chunk of memory		
Smallest *guaranteed* continuous chunk of memory		
Data type returned by:	`array2D[1]`	`array2L[1]`
Number of memory accesses to get `int` in the *BEST* case		
Number of memory accesses to get `int` in the *WORST* case		

Procedures and the Stack

The Stack is a region in memory which starts from the highest memory address and grows downwards when necessary as a programs executes. We consider the region with the highest address the Stack "bottom" and the region with the lowest address the Stack "top". **%rsp** is a dedicated special register which points to the current Stack top.

In x86-64, the Stack can be broken down into Stack Frames of functions. Consider the following lines of code:

```
int main() {
  int x = 351;
  foo(1,2,3,4,5,6,7);
}
void foo(int arg1, int arg2, …,int arg7){
  int y = 333;
}
```



Shown in the figure on the right are the stack frames of `main` and `foo` right before `foo` returns:

- Main
  - Return address (not pictured)
  - Potentially saved registers (not pictured)
  - Local variables
  - Arguments for called procedures
- Foo
  - Return address to main
  - Potentially saved registers
  - Local variables

Consider the following x86-64 assembly and C code for the recursive function `rfun`.

```
// Recursive function rfun
long rfun(char *s) {
  if (*s) {
    long temp = (long)*s;
    s++;
    return temp + rfun(s);
  }
  return 0;
}

// Main Function - program entry
int main(int argc, char **argv) {
  char *s = "CSE351";
  long r = rfun(s);
  printf("r: %ld\n", r);
}
```

```
00000000004005e6 <rfun>:
  4005e6: 0f b6 07              movzbl (%rdi),%eax
  4005e9: 84 c0                 test %al,%al
  4005eb: 74 13                 je 400600 <rfun+0x1a>
  4005ed: 53                    push %rbx
  4005ee: 48 0f be d8           movsbq %al,%rbx
  4005f2: 48 83 c7 01           add $0x1,%rdi
  4005f6: e8 eb ff ff ff        callq 4005e6 <rfun>
  4005fb: 48 01 d8              add %rbx,%rax
  4005fe: eb 06                 jmp 400606 <rfun+0x20>
  400600: b8 00 00 00 00        mov $0x0,%eax
  400605: c3                    retq
  400606: 5b                    pop %rbx
  400607: c3                    retq
```

a) In terms of the C function, what value is being saved on the stack?

b) What is the return address to `rfun` that gets stored on the stack during the recursive calls (in hex)?

c) Assume `main` calls `rfun` with `char *s = "CSE 351"` and then prints the result using the `printf` function, as shown in the C code above. Assume `printf` does not call any other procedure. Starting with (and including) `main`, how many total stack frames are created, and what is the maximum depth of the stack?

d) Assume `main` calls `rfun` with `char *s = "CSE 351"`, as shown in the C code. After `main` calls `rfun`, we find that the return address to `main` is stored on the stack at address `0x7fffffffdb38`. On the first call to `rfun`, the register `%rdi` holds the address `0x4006d0`, which is the address of the input string "CSE 351" (i.e. `char *s = 0x4006d0`) during the **fourth** call to `rfun`.

*For each address in the stack diagram below, fill in both the **value** and a **description** of the entry.*

Memory Address	Value	Description
0x7fffffffdb48	Unknown	%rsp when main is entered
0x7fffffffdb38	0x400616	Return address to main
0x7fffffffdb30	Unknown	Original %rbx
0x7fffffffdb28		
0x7fffffffdb20		
0x7fffffffdb18		
0x7fffffffdb10		
0x7fffffffdb08		
0x7fffffffdb00		

Address	Value (hex)
%rsp+15	00
%rsp+14	00
%rsp+13	00
%rsp+12	00
%rsp+11	00
%rsp+10	40
%rsp+9	AF
%rsp+8	3B
%rsp+7	
%rsp+6	
%rsp+5	
%rsp+4	
%rsp+3	
%rsp+2	
%rsp+1	
%rsp+0	

Buffer Overflow

Consider the following C program:

```
void main() {
  read_input();
}

int read_input() {
  char buf[8];
  gets(buf);
  return 0;
}
```

Here is a diagram of the stack in `read_input()` right before the call to `gets()`:

a) What is the value of the return address stored on the stack?

Assume that the user inputs the string "`jklmnopqrs`"

b) Write the values in the stack before the "return 0;" statement is executed. Cross out the values that were overwritten and write in their new values.
(Hint: use the ASCII table at the bottom to convert from letters to bytes)

c) What is the new return address after the call to `gets()`?

d) Where will execution jump to after the "`return 0;`"?

e) How many characters would we have to enter into the command line to overwrite the return address to `0x6A6B6C6D6E6F`?

f) Create a string that will overwrite the return address, setting it to `0x6A6B6C6D6E6F`

In Lab 3, we are given a tool called `sendstring`, which converts hex digits into the actual bytes

```
>echo "61 62 63" | ./sendstring
abc
```

g) If we want to overwrite the return address to a stack address like 0x7FFFFFAB1234, we need to use a tool like sendstring to send the correct bytes.
Why can't we just manually type the characters like we did earlier with "`jklmnopqrs`"?

Char	Hex
a	61
b	62
c	63
d	64
e	65
f	66
g	67
h	68
i	69
j	6A
k	6B
l	6C
m	6D
n	6E
o	6F
p	70
q	71
r	72
s	73
t	74
u	75
v	76
w	77
x	78
y	79
z	7A

Check out the Lab 3 video on
Phase 0 before you start the lab!
It's linked on the Lab 3 page