# Chapter 16
## Pointers and Arrays

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## Pointers and Arrays

We've seen examples of both of these
in our LC-3 programs; now we'll see them in C

**Pointer**

- Address of a variable in memory
- Allows us to indirectly access variables
  - In other words, we can talk about its *address* rather than its *value*

**Array**

- A list of values arranged sequentially in memory
- Expression `a[4]` refers to the 5th element of the array `a`

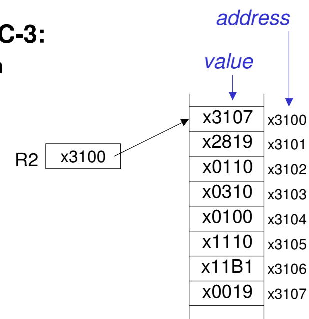


## Address vs. Value

Sometimes we want to deal with the address of a memory location, rather than the value it contains

Adding a column of numbers in LC-3:

- R2 contains address of first location
- Read value, add to sum, and increment R2 until all numbers have been processed




R2 is a pointer

- It contains the address of data



## Another Need for Addresses

Consider the following function that's supposed to swap the values of its arguments.

```
void swap(int first, int second){
  int temp = first;
  first = second;
  second = temp;
}
 int main(){
   int a = 3;
   int b = 4;
  swap(a,b);
 }
```

## Executing the Swap Function

*before call* / *after call*

| before call | | after call | | |
|---|---|---|---|---|
| | | 3 | temp | swap |
| 3 | first | 4 | first | swap |
| 4 | second | 3 | second | swap |
| 4 | b | 4 | b | main |
| 3 | a | 3 | a | main |

These values changed...

...but these did not.

Swap needs addresses of variables outside its own activation record



## Pointers in C

**C lets us talk about and manipulate pointers as variables and in expressions.**

### Declaration

```
int *p;   /* p is a pointer to an int */
```

**A pointer in C is always a pointer to a particular data type:** `int*`, `double*`, `char*`, **etc.**

### Operators

- `*p` -- returns the value pointed to by p
- `&z` -- returns the address of variable z



## Example

```
int main(){
int i;
int *ptr;

i = 4;
ptr = &i;
*ptr = *ptr + 1;
printf("%d\n", i);

}
```

- store the value 4 into the memory location associated with i
- store the address of "i" into the memory location associated with ptr
- read the contents of memory at the address stored in ptr and increment it by 1
- Value of i will be "5", because "i" was modified indirectly via ptr

| Address | Value | |
|---|---|---|
| xEFF9 | | |
| xEFFA | | |
| xEFFB | xEFFC | ptr |
| xEFFC | ~~4~~ 5 | i |
| xEFFD | | |
| xEFFE | | |



## Example: LC-3 Code

```
; i is (offset 1), ptr (offset 0 i.e. the last local variable added to
stack frame)
;i = 4;
      AND   R0, R0, #0    ; clear R0
      ADD   R0, R0, #4    ; put 4 in R0
      ADD   R6, R6, #-1   ;adjust stack pointer
      STR   R0, R6, #0    ; store in I on top of stack
; int *ptr = &i;
      ADD   R0, R6, #0    ; R0 = R6 + 0 (addr of i)
      ADD   R6, R6, -1    ;create space for ptr
      STR   R0, R6, #0    ; store addr of i in ptr
      AND   R5, R5, #0
      ADD   R5, R6, #0   ;main's frame pointer
; *ptr = *ptr + 1;
      LDR   R0, R5, #0    ; R0 = ptr
      LDR   R1, R0, #0    ; load contents (*ptr)
      ADD   R1, R1, #1    ; add one
      STR   R1, R0, #0    ; store to *ptr
```

## Pointers as Arguments

Passing a pointer into a function allows the function to read/change memory outside its activation record

```
void swap(int *first, int *second)
{
  int temp = *first;
  *first = *second;
  *second = temp;
}
```

Arguments are integer pointers. Caller passes addresses of variables that it wants function to change



## Passing Pointers to a Function

main() wants to swap the values of "a" and "b" passes the addresses to swap():

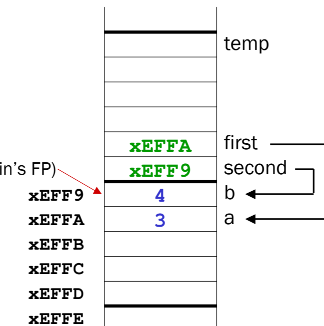
```
swap(&a, &b);
```

Code for passing arguments:

```
ADD R0, R5, #0 ; addr of b
ADD R6, R6, #-1;
STR R0, R6, #0

ADD R0, R5, #1  ; addr of a
ADD R6, R6, #-1;
STR R0, R6, #0
```

R5 (Main's FP)



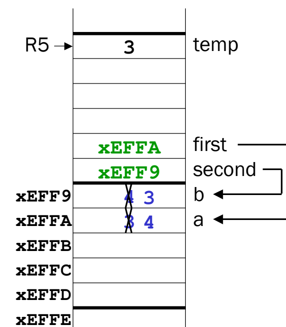



## Code Using Pointers

Inside the swap() routine

```
; int temp = *first;
LDR  R0, R5, #4 ; R0=xEFFA
LDR  R1, R0, #0 ; R1=M[xEFFA]=3
STR  R1, R5, #0 ; temp=3
; *first = *second;
LDR  R1, R5, #5 ; R1=xEFF9
LDR  R2, R1, #0 ; R2=M[xEFF9]=4
STR  R2, R0, #0 ; M[xEFFA]=4

 ; *second = temp;
 LDR  R2, R5, #0 ; R2=3
 STR  R2, R1, #0 ; M[xEFF9]=3
```






## Using Arguments for Results

Pass address of variable where you want result stored

- Useful for multiple results
- Example:
  - Return value via pointer
  - This solves the mystery of the '&' for calling scanf():

```
scanf("%d %d", &data1, &data2);
```

read decimal integers into `data1` and `data2`

## Null Pointer

Sometimes we want a pointer that points to nothing.
In other words, we declare a pointer, but we're not ready to actually point to something yet.

```
int *p;
p = NULL;  /* p is a null pointer */
```

`NULL` is a predefined macro that contains a value that a non-null pointer should never hold.

- Often, NULL = 0, because Address 0 is not a legal address for most programs on most platforms
- Dereferencing a NULL pointer: program crash!
  - `int *p = NULL;  printf("%d", *p);` // CRASH!
  - Output: Segmentation fault



## Examples: Pointer Problems

What does this do?

```
int *x;
*x = 10;
```

Answer: writes "10" into a random location in memory

What's wrong with:

```
int* func(){
  int x = 10;
  return &x;
}
```

Answer: storage for "x" disappears on return, so the returned pointer is dangling

A dangling pointer is a pointer to storage element(int, char, double etc) that is no longer allocated



## Declaring Pointers

The * operator binds to the variable name, not the type

All the same:

- `int* x, y;`
- `int *x, y;`
- `int *x; int y;`

Suggested solution: Declare only one variable per line

- Avoids this problem
- Easier to comment
- Clearer
- Don't worry about "saving space"



## Arrays

How do we allocate a group of memory locations?

- Character string
- Table of numbers

How about this?

```
int num0;
int num1;
int num2;
int num3;
```

Not too bad, but...

- What if there are 100 numbers?

Fortunately, C has *array declaration*.

```
int num[4];
```

Declares a sequence of four integers, referenced by:
`num[0]`, `num[1]`, `num[2]`, `num[3]`.

## Array Syntax

**Declaration**

```
type  variable[num_elements];
```

all array elements are of the same type

number of elements must be known at compile-time

**Array Reference**

```
variable[index];
```

i-th element of array (starting with zero); no limit checking at compile-time or run-time



## Array as a Local Variable

Array elements are allocated as part of the activation record

```
int grid[10];
```

First element (`grid[0]`) is at lowest address of allocated space

grid[0]
grid[1]
grid[2]
grid[3]
grid[4]
grid[5]
grid[6]
grid[7]
grid[8]
grid[9]



## LC-3 Code for Array References

```
; x = grid[3] + 1
 ADD R0, R5, #1   ; R0 = &grid[0]
 LDR R1, R0, #3   ; R1 = grid[3]
 ADD R1, R1, #1   ; R1 = R1 + 1
 STR R1, R5, #0   ; x = R1

; grid[6] = 5;
 AND R0, R0, #0
 ADD R0, R0, #5   ; R0 = 5
 ADD R1, R5, #1   ; R1 = &grid[0]
 STR R0, R1, #6   ; grid[6] = R0
```

R5 → x
grid[0]
grid[1]
grid[2]
grid[3]
grid[4]
grid[5]
grid[6]
grid[7]
grid[8]
grid[9]



## More LC-3 Code

```
; grid[x+1] = grid[x] + 2
 LDR R0, R5, #0   ; R0 = x
 ADD R1, R5, #1   ; R1 = &grid[0]
 ADD R1, R0, R1   ; R1 = &grid[x]
 LDR R2, R1, #0   ; R2 = grid[x]

 ADD R2, R2, #2   ; add 2

 LDR R0, R5, #0   ; R0 = x
 ADD R0, R0, #1   ; R0 = x+1
 ADD R1, R5, #1   ; R1 = &grid[0]
 ADD R1, R0, R1   ; R1 = &grix[x+1]
 STR R2, R1, #0   ; grid[x+1] = R2
```

R5 → x
grid[0]
grid[1]
grid[2]
grid[3]
grid[4]
grid[5]
grid[6]
grid[7]
grid[8]
grid[9]

## Passing Arrays as Arguments

C passes arrays by address

- the address of the array (i.e., of the first element) is written to the function's activation record
- otherwise, would have to copy each element

```
int main()
{
  int numbers[MAX_NUMS];
  …
  mean = average(numbers, MAX_NUMS);
  …
}
int average(int values[], int size)
{
  int index, sum = 0;
  for (index = 0; index < size; index++) {
    sum = sum + values[index];
  }
  return (sum / size);
}
```

This must be a constant, e.g., `#define MAX_NUMS 10`



## More on Passing Arrays

No run-time length information

- C doesn't track length of arrays
- No Java-like `values.length` construct
- Thus, you need to pass length or use a sentinel

```
int average(int values[], int size)
{
  int index, sum;
  for (index = 0; index < size; index++) {
    sum = sum + values[index];
  }
  return (sum / size);
}
```



## Relationship between Arrays and Pointers

An array name is essentially a pointer to the first element in the array

```
    char data[10];
i.e. data = addr where first element is located
          = &data[0]
```

Example:

```
    char data[10];
    char *cptr;
    cptr = data; /* points to data[0] */
```



## Correspondence between Ptr and Array Notation

Given the declarations on the previous page, each line below gives three equivalent expressions:

| | | |
|---|---|---|
| `cptr` | `data` | `&data[0]` |
| `(cptr + n)` | `(data + n)` | `&data[n]` |
| `*cptr` | `*data` | `data[0]` |
| `*(cptr + n)` | `*(data + n)` | `data[n]` |

## Beware

**Array are not the same as pointers although they may look like**

**what is the difference between arrays and pointers?**

- Arrays automatically allocate space, but can't be relocated or resized.
- Pointers must be explicitly assigned to point to allocated space but can be reassigned (i.e. pointed at different objects) at will, and have many other uses besides serving as the base of blocks of memory.



## Pointer Arithmetic: Subtraction and Equality

Nasty, but C allows it:

```
void function(int* start, int* end)
{
  int i;
  while (end - start >= 0) {
    *start = 0;
    start++;
  }
}
In function main():
int array[10];
function(&array[0], &array[9]);
```

**Don't do this!**

Alternative: `while (end != start) {`

- Significantly better, but still too nasty
- What if start is > end, or not part of same array?



## More on Pointer Arithmetic

### Address calculations depend on size of elements

- In our LC-3 code, we've been assuming one word per element
  - e.g., to find 4th element, we add 4 to base address
- It's ok, because we've only shown code for int, which takes up one word (equal to machine width).
- If `double`, we'd have to add 8 to find address of 4th element.

**C does size calculations under the covers, depending on size of item being pointed to:**

```
double x[10];
double *y = x;
*(y + 3) = 100;
```

allocates 20 words (2 per element)

same as x[3] -- base address plus 6



## Common Pitfalls with Arrays in C

### Overrun array limits

- There is no checking at run-time or compile-time to see whether reference is within array bounds

```
int array[10];
int i;
for (i = 0; i <= 10; i++) {
  array[i] = 0;
}
```

- Remember, C does not track array length

## C vs. Java

C Pointers makes it unsafe as there is no compile time checking on:

- Dereferencing a null pointer
- Having dangling pointer
- Can easily right to memory space beyond what you declared
  - No limit checking for array length

Java removes unsafe features by not

- supporting the unary '&' address operator
- supporting address arithmetic on references
  - i.e. does not allow integer values to be added/subtracted to references



## Strings

A string is an Null-Terminated Character Array

Allocate space for a string just like any other array:

```
char outputString[16];
```

Space for string must contain room for terminating zero

Special syntax for initializing a string:

```
char outputString[] = "Result = ";
```

...which is the same as:

```
outputString[0] = 'R';
outputString[1] = 'e';
outputString[2] = 's';
...
outputString[9] = '\0'; // Null terminator
```



## I/O with Strings

Printf and scanf use "%s" format character for string

Printf -- print characters up to terminating zero

```
printf("%s", outputString);
```

Scanf -- read characters until whitespace, store result in string, and terminate with zero

```
scanf("%s", inputString);
```

Why no & operator?



## Strings

Although there is not string data type in C, C has library <string.h> that can perform actions on strings.

All the functions in <string.h> have parameters or return values as character arrays terminated with null character

## String Length - Array Style

```
int strlen(char str[])
{
  int i = 0;
  while (str[i] != '\0') {
    i++;
  }
  return i;
}
```



## String Length - Pointer Style

```
int strlen(char* str)
{
  int i = 0;
  while (*str != '\0') {
    i++;
    str++;
  }
  return i;
}
```

**Note:** array and pointer declarations interchangeable as function formal parameters because the whole array is never actually passed to a function (the address of the array is)



## Usage of strlen

```
#include<string.h>
#include <stdio.h>
int main(){
  char array[] = "Hello";
  for(i = 0; i <  strlen(array);i++){
    printf("%c\n",array[i]);
  }
}
```

**Output:**
**H**
**e**
**l**
**l**
**o**



## String Copy - Array Style

```
void strcpy(char dest[], char src[])
{
  int i = 0;
  while (src[i] != '\0') {
    dest[i] = src[i];
    i++;
  }
  dest[i] = '\0'
}
```

## String Copy - Array Style #2

```
void strcpy(char dest[], char src[])
{
  int i = 0;
  while ((dest[i] = src[i]) != '\0') {
    i++;
  }
}
```



## String Copy - Pointer Style

```
void strcpy(char* dest, char* src)
{
  while ((*dest = *src) != '\0') {
    dest++;
    src++;
  }
}
```



## String Copy - Pointer Style #2

```
void strcpy(char* dest, char* src)
{
  while ((*dest++ = *src++) != '\0') {
    // nothing
  }
}
```

**Difficult to read**

- "Experienced C programmers would prefer…" - K&R
- However confusing: try avoid this type of code

**What happens if `dest` is too small?**

- Bad things…



## C String Library

**C has a limited string library**

- All based on null-terminated strings
- #include <string.h> to use them

**Functions include**

- `int strlen(char* str)`
- `void strcpy(char* dest, char* src)`
- `int strcmp(char* s1, char* s2)`
  - Returns 0 on equal, -1 or 1 if greater or less
  - Remember, 0 is false, so equal returns false!
- `strcat(char* dest, char* src)`
  - string concatenation (appending two strings)
- `strncpy(char* dest, char* src, int max_length)`
- `strncmp(char* s1, char* s2, int max_length)`
- `strncat(char* dest, char* src, int max_length)`
- Plus some more…

## String Declaration

**What's the difference between:**

- char amessage[ ] = "message"
- char *pmessage = "message"

**Answer:**

- char amessage[ ] = "message" // single array

`m e s s a g e \0`

- char *pmessage = "message" // pointer and array

`[ ] → m e s s a g e \0`



## Main(), revisited

Main supports command line parameters

In Java

```
public static void main(String[] args)
```

In C:

```
int main(int argc, char *argv[])
{
}
```

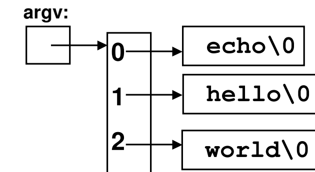
An array of strings

By convention argv[0] is name by which program is invoked so argc is atleast 1.

Example:

gcc – o echo.c echo

echo hello world






## Disassembler program – hw5part2

```
int main(int argc, char **argv) {
 FILE* f;

 if (argc != 2) {
  printf("Usage: %s <obj-file>\n", argv[0]);
  return 1;
 }

 f = fopen(argv[1], "r");
 if (f == NULL) {
  printf("Error opening file %s\n", argv[1]);
  return 1;
 }
……//rest of the code

}
```



## Evaluation Order special case in C

**What does this do?**

```
void func(int x, int y) { printf("%d %d", x, y); }

int main()
{
  int x = 3;
  func(x, x++);
  …
}
```

**Answer: undefined!**

- Displays either "3 3" or "4 3"
- Why? C does not define order of evaluation in such a case
- Depends on compiler writer
- Suggestion: *don't* modify variable in parameter list

## Logical AND Evaluation

```
int func(int x)
{
  printf("%d", x);
  return x;
}

int main()
{
  int x = 0;
  int y = 1;
  if (func(x) && func(y)) {
    …
  }
}
```

**Answer: Prints just "0"**

- **Why? If left of "&&" operator is false, it *does not* evaluate right side**
- **"||" operator similar**
- **Java has similar semantics**