Chapter 16
Pointers and Arrays

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

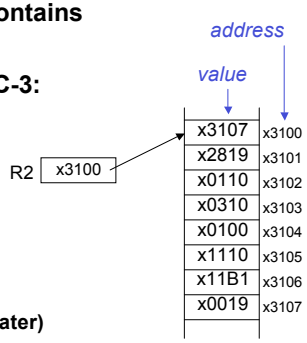
- A list of values arranged sequentially in memory
- Expression `a[4]` refers to the 5th element of the array `a`
- Example: video memory in BreakOut (2D)

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
- (It's also an array, but more on that later)

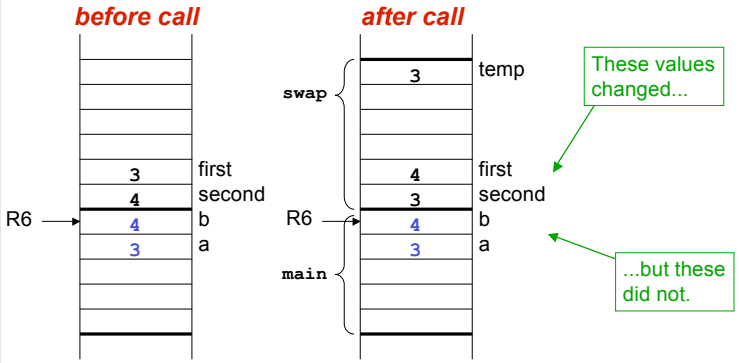
Another Need for Addresses

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

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

What's wrong with this code?

Executing the Swap Function



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 i;
int *ptr;

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

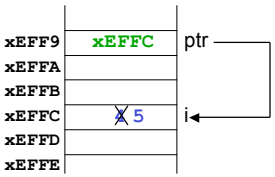
store the value 4 into the memory location associated with i

store the address of "i" into the memory location associated with ptr

read the contents of memory at the address stored in ptr

print the value "5", becaue "i" was modified indirectly via ptr

store the result into memory at the address stored in ptr



Example: LC-3 Code

```
; i is 1st local (offset 0), ptr is 2nd (offset 1)
; i = 4;
      AND  R0, R0, #0   ; clear R0
      ADD  R0, R0, #4   ; put 4 in R0
      STR  R0, R6, #0   ; store in i
;ptr = &i;
      ADD  R0, R6, #0   ; R0 = R6 + 0 (addr of i)
      STR  R0, R6, #1   ; store in ptr
; *ptr = *ptr + 1;
      LDR  R0, R6, #1   ; 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;
}
```

How would you do this in Java?

All arguments in C are pass-by-value. Also true in Java, but Java has reference types

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

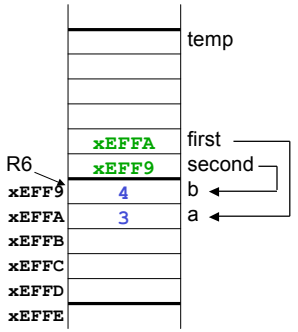
Passing Pointers to a Function

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

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

Code for passing arguments:

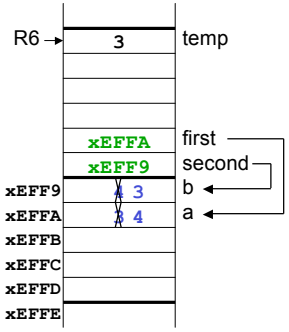
```
ADD R0, R6, #0 ; addr of b
STR R0, R6, #-1
ADD R0, R6, #1  ; addr of a
STR R0, R6, #-2
```



Code Using Pointers

Inside the swap() routine

```
; int temp = *first;
LDR  R0, R6, #4 ; R0=xEFFA
LDR  R1, R0, #0 ; R1=M[xEFFA]=3
STR  R1, R6, #0 ; temp=3
; *first = *second;
LDR  R1, R6, #5 ; R1=xEFF9
LDR  R2, R1, #0 ; R1=M[xEFF9]=4
LDR  R0, R6, #4 ; R0=xEFFA
STR  R2, R0, #0 ; M[xEFFA]=4
; *second = temp;
LDR  R2, R6, #0 ; R2=3
LDR  R1, R6, #5 ; R1=xEFF9
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**
  - **Return status code as function result**

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!**

Pointer Problems

What does this do?

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

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

- **What would java do?**

What's wrong with:

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

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

- **What would java do?**

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?**
- **How do we write a loop to process each number?**

Fortunately, C gives us a better way -- the *array*.

```
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];
```

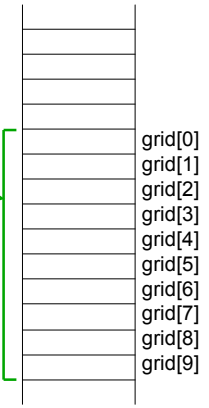
i-th element of array (starting with zero);
no limit checking at compile-time or run-time

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

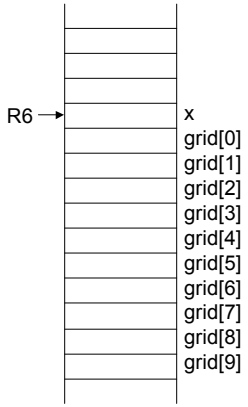


LC-3 Code for Array References

```
; x = grid[3] + 1
ADD R0, R6, #1   ; R0 = &grid[0]
LDR R1, R0, #3   ; R1 = grid[3]
ADD R1, R1, #1   ; plus 1
STR R1, R6, #0   ; x = R1

; grid[6] = 5;
AND R0, R0, #0
ADD R0, R0, #5   ; R0 = 5
ADD R1, R6, #1   ; R1 = &grid[0]
STR R0, R1, #6   ; grid[6] = R0
```

Compiler can combine

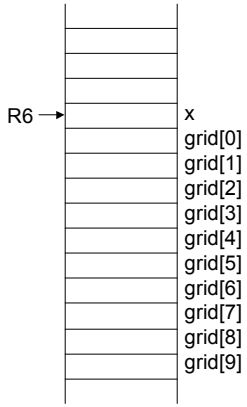


More LC-3 Code

```
; grid[x+1] = grid[x] + 2
LDR R0, R6, #0   ; R0 = x
ADD R1, R6, #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, R6, #0   ; R0 = x
ADD R0, R0, #1   ; R0 = x+1
ADD R1, R6, #1   ; R1 = &grid[0]
ADD R1, R0, R1   ; R1 = &grix[x+1]
STR R2, R1, #0   ; grid[x+1] = R2
```



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];
char *cptr;

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

Difference:

Can change the contents of cptr, as in

```
cptr = cptr + 1;
```


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]`

Pointer Subtraction and Equality

Nasty, but C allows it:

```
void function(int* start, int* end)
{
  int i;
  while (end - start >= 0) {
    *start = 0;
    start++;
  }
}
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.
- 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

Declaration with variable size

- Size of array must be known at compile time

```
void func(int num_elements)
{
  int temp[num_elements];
  …
}
```

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?

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;
}
```


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'
}
```

Clean, clear

String Copy - Array Style #2

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

Use of assignment in while

- Harder to read, in my opinion

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
- I disagree: please avoid this type of code (really)

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…

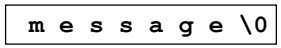
String Declaration Nastiness

What's the difference between:

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

Answer:

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



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

Main(), revisited

Main supports command line parameters

- Much like Java's

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

Main supports command line parameters:

```
int main(int argc, char *argv[])
{
  int i;
  for (i = 0; i<argc; i++) {
    printf("%s\n", argv[i]);
  }
}
```

An array of strings

Displays each command-line argument

- Zero-parameter is the program name