

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 mechanism to group multiple elements of a homogeneous type
- its elements allocated sequentially in memory
- Examples
 - `int a[5];` is a declaration of an integer array with 5 elements
 - Expression `a[0]` refers to the 1st element of the array `a`
 - Expression `a[4]` refers to the 5th (i.e., last) element of the array `a`

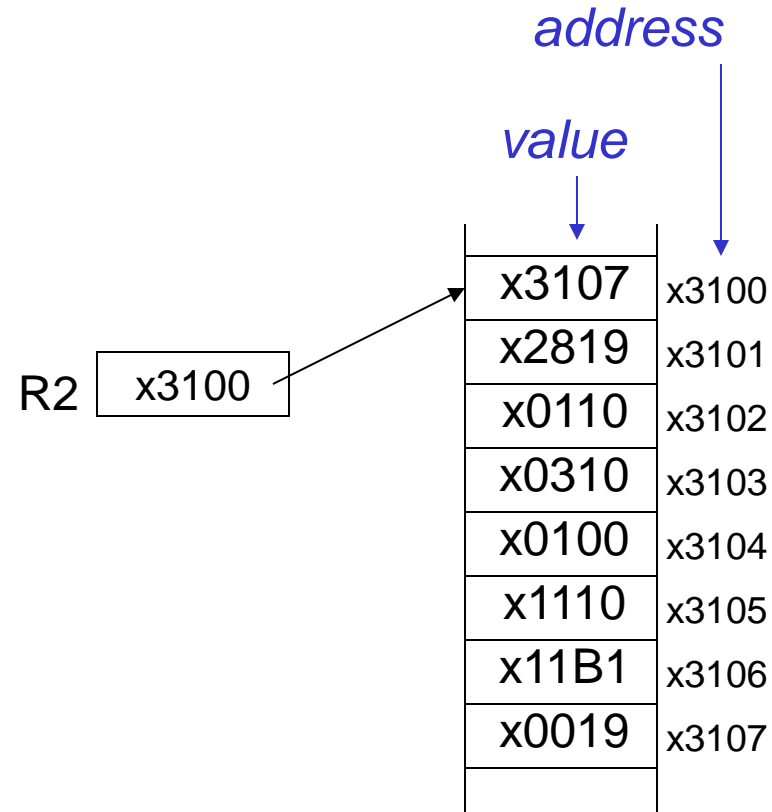
Address vs. Value

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

Recall example from Chapter 6: adding a column of numbers.

- 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 we're interested in.



Another Need for Addresses

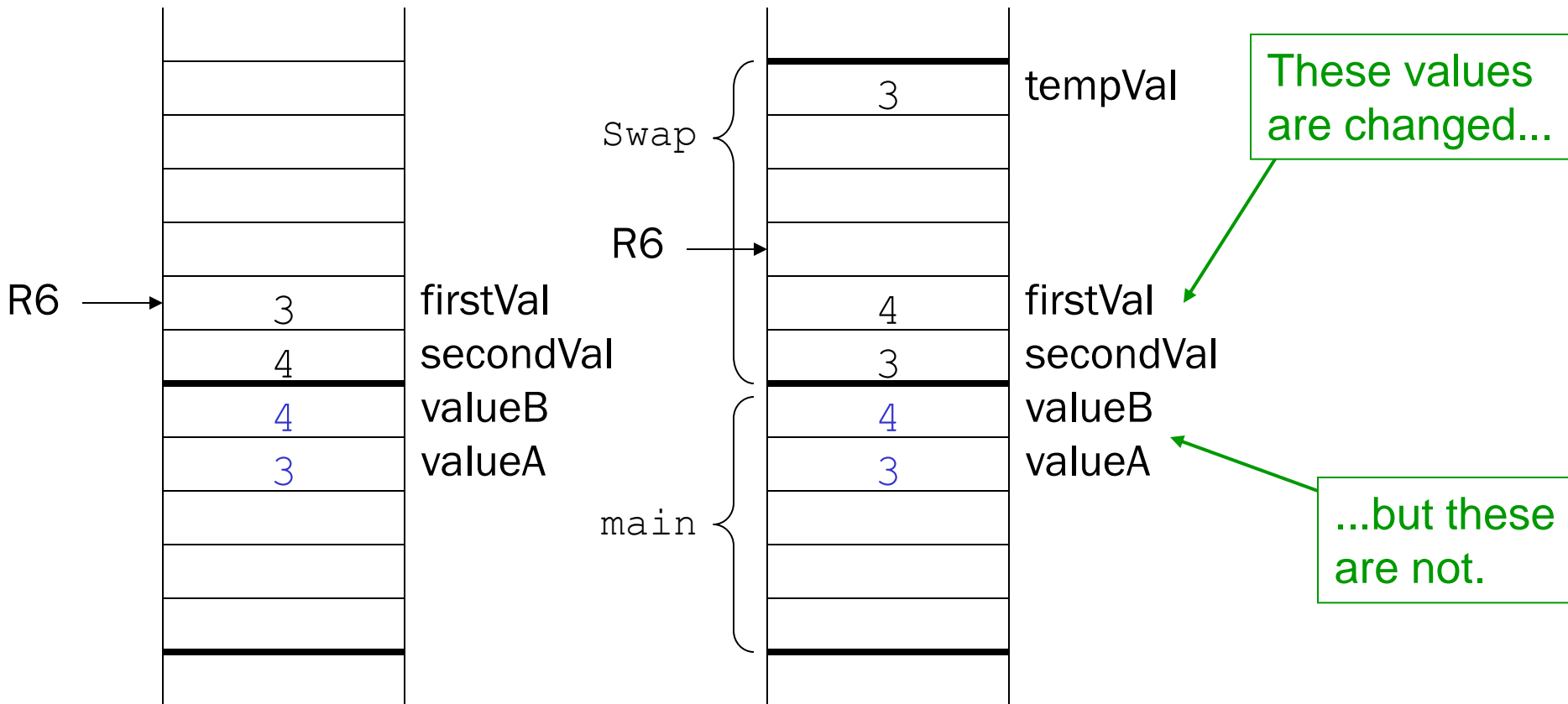
Consider the following function that's supposed to swap the values of its arguments.

```
void Swap(int firstVal, int secondVal)
{
    int tempVal = firstVal;
    firstVal = secondVal;
    secondVal = tempVal;
}
```

Executing the Swap Function

before call

after call



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;
```

store the value 4 into the memory location associated with i

```
i = 4;
```

```
ptr = &i;
```

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

```
*ptr = *ptr + 1;
```

read the contents of memory at the address stored in 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, R5, #0 ; store in i

; ptr = &i;

ADD R0, R5, #0 ; R0 = R5 + 0 (addr of i)

STR R0, R5, #-1 ; store in ptr

*; *ptr = *ptr + 1;*

LDR R0, R5, #-1 ; R0 = ptr

LDR R1, R0, #0 ; load contents (*ptr)

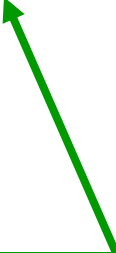
ADD R1, R1, #1 ; add one

STR R1, R0, #0 ; store result where R0 points

Pointers as Arguments

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

```
void NewSwap(int *firstVal, int *secondVal)
{
    int tempVal = *firstVal;
    *firstVal = *secondVal;
    *secondVal = tempVal;
}
```



**Arguments are integer pointers.
Caller passes addresses of variables that it wants the callee to change.**

Passing Pointers to a Function

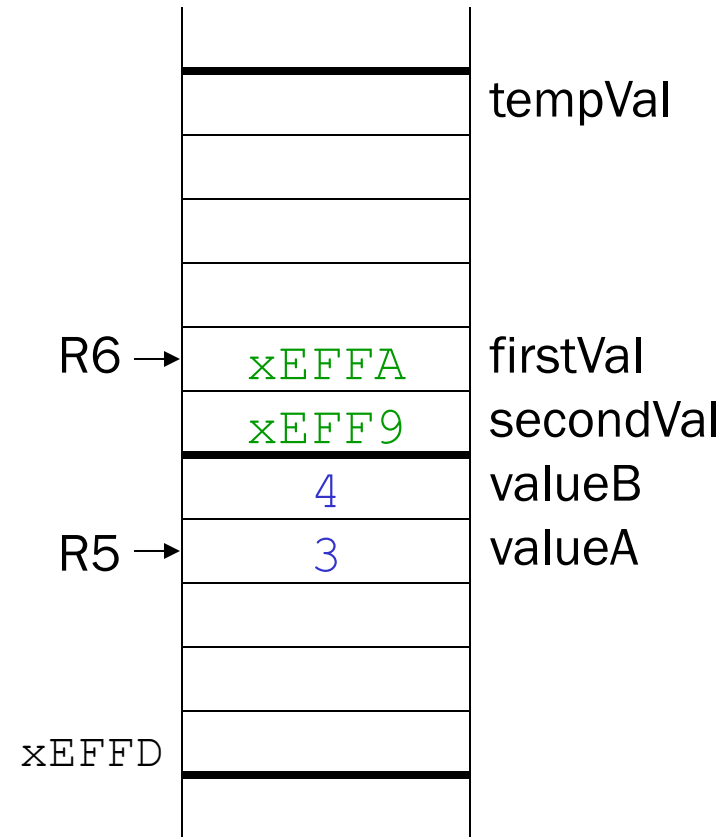
main() wants to swap the values of valueA and valueB

passes the addresses to NewSwap:

```
NewSwap(&valueA, &valueB);
```

Code for passing arguments:

```
ADD R0, R5, #-1 ; addr of valueB
ADD R6, R6, #-1 ; push
STR R0, R6, #0
ADD R0, R5, #0 ; addr of valueA
ADD R6, R6, #-1 ; push
STR R0, R6, #0
```

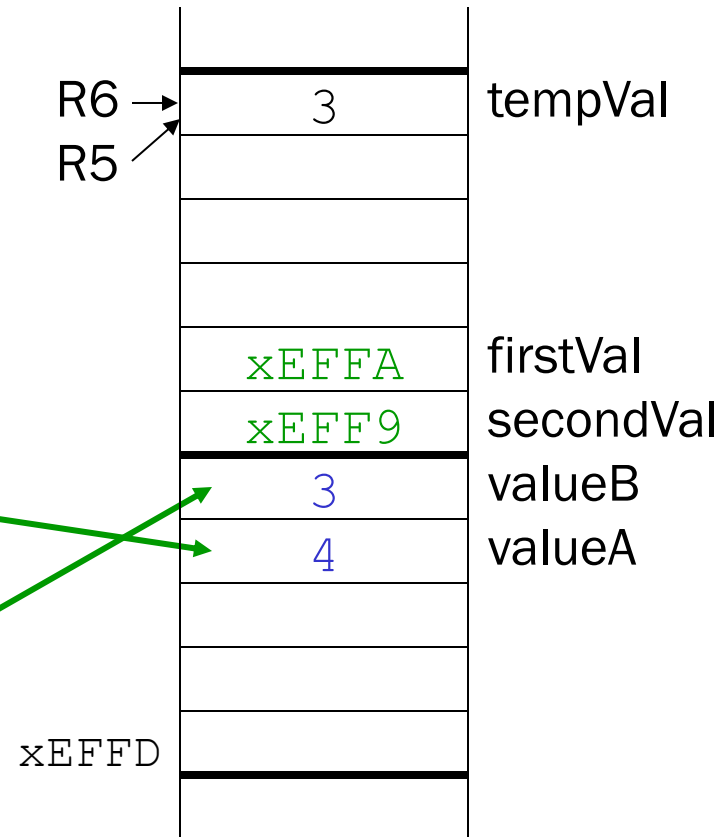


Code Using Pointers

Inside the NewSwap routine

```

; int tempVal = *firstVal;
LDR  R0, R5, #4 ; R0=xEFFA
LDR  R1, R0, #0 ; R1=M[xEFFA]=3
STR  R1, R5, #0 ; tempVal=3
; *firstVal = *secondVal;
LDR  R1, R5, #5 ; R1=xEFF9
LDR  R2, R1, #0 ; R2=M[xEFF9]=4
STR  R2, R0, #0 ; M[xEFFA]=4
; *secondVal = tempVal;
LDR  R2, R5, #0 ; R2=3
STR  R2, R1, #0 ; M[xEFF9]=3
    
```



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.**

Using Arguments for Results

Pass address of variable where you want result stored

- useful for multiple results

Example:

- return multiple values by passing their pointers
- return status code by the usual function return value

This solves the mystery of why ‘&’ with argument to scanf:

```
scanf("%d ", &dataIn);
```



**read a decimal integer
and store in dataIn**

Syntax for Pointer Operators

Declaring a pointer

```
type *ptr;  
type* ptr;
```

Either of these work -- whitespace doesn't matter.
Type of variable is `int*` (integer pointer), `char*` (char pointer), etc.

Getting the address of a variable

```
ptr = &var;
```

Must be applied to a memory object, such as a variable.
In other words, `&3` or `&(a + b)` is not allowed.

Dereferencing

Can be applied to any expression. All of these are legal:

<code>*ptr</code>	contents of mem loc pointed to by ptr
<code>**ptr</code>	contents of mem loc pointed to by mem loc pointed to by ptr
<code>*3</code>	contents of memory location 3 (typically an error)

Example using Pointers

IntDivide performs integer division returning results (quotient and remainder) via pointers. (Returns -1 if divide by zero.)

```
int IntDivide(int x, int y, int *quoPtr, int *remPtr);

main()
{
    int dividend, divisor; /* numbers for divide op */
    int quotient, remainder; /* results */
    int error;
    /* ...code for dividend, divisor input removed... */
    error = IntDivide(dividend, divisor,
                     &quotient, &remainder);
    /* ...remaining code removed... */
}
```

C Code for IntDivide

```
int IntDivide(int x, int y, int *quoPtr, int *remPtr)
{
    if (y != 0) {
        *quoPtr = x / y; /* quotient in *quoPtr */
        *remPtr = x % y; /* remainder in *remPtr */
        return 0;
    }
    else
        return -1;
}
```


Arrays

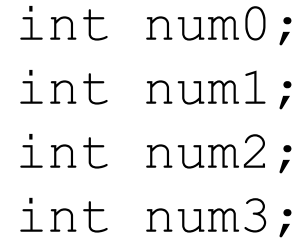
How do we allocate a group of memory locations?

- character string
- table of numbers

How about this?

Not too bad, but...

- what if there are 100 numbers?
- how do we write a loop to process each number?



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

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[i];
```

(i+1)-th element of array (starting with zero);
no limit checking at compile-time or run-time

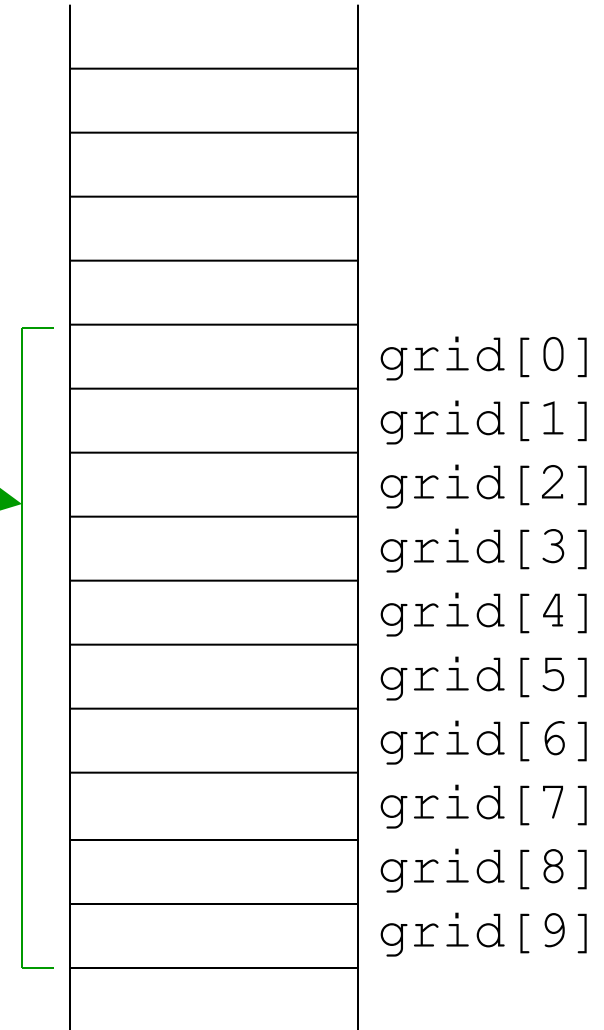
Array as a Local Variable

Array elements are allocated as part of the activation record.

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

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

If `grid` is first variable allocated, then `R5` will point to `grid[9]`.

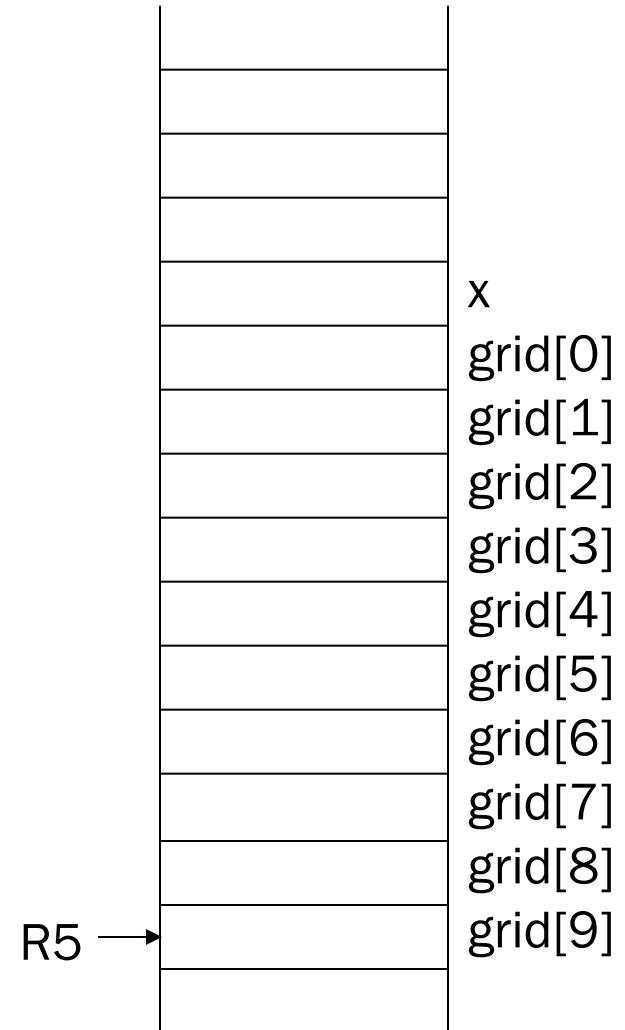


LC-3 Code for Array References

```

; x = grid[3] + 1
  ADD R0, R5, #-9   ; R0 = &grid[0]
  LDR R1, R0, #3    ; R1 = grid[3]
  ADD R1, R1, #1    ; plus 1
  STR R1, R5, #-10  ; x = R1

; grid[6] = 5;
  AND R0, R0, #0
  ADD R0, R0, #5    ; R0 = 5
  ADD R1, R5, #-9   ; R1 = &grid[0]
  STR R0, R1, #6    ; grid[6] = R0
    
```

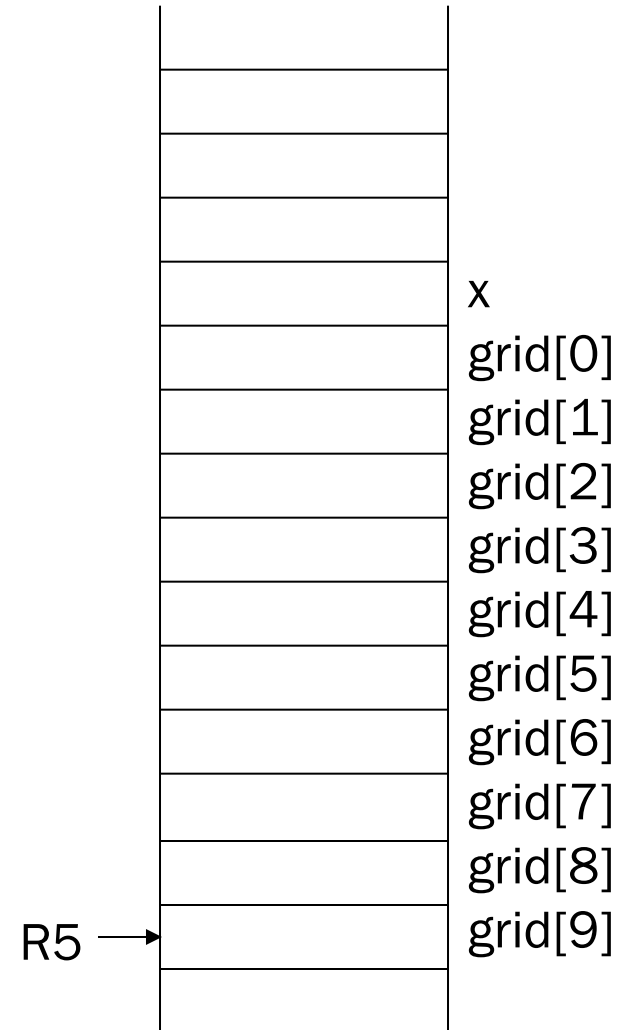


More LC-3 Code

```

; grid[x+1] = grid[x] + 2
LDR R0, R5, #-10 ; R0 = x
ADD R1, R5, #-9 ; 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, #-10 ; R0 = x
ADD R0, R0, #1 ; R0 = x+1
ADD R1, R5, #-9 ; R1 = &grid[0]
ADD R1, R0, R1 ; R1 = &grid[x+1]
STR R2, R1, #0 ; grid[x+1] = R2
    
```



Passing Arrays as Arguments

C passes arrays by reference

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

```
main() {  
    int numbers[MAX_NUMS];  
    ...  
    mean = Average(numbers);  
    ...  
}  
  
int Average(int inputValues[MAX_NUMS]) {  
    ...  
    for (index = 0; index < MAX_NUMS; index++)  
        sum = sum + indexValues[index];  
    return (sum / MAX_NUMS);  
}
```

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

A String is an Array of Characters

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[16] = "Result = ";
```

...which is the same as:

```
outputString[0] = 'R';  
outputString[1] = 'e';  
outputString[2] = 's';  
...  
outputString[7] = '=';  
outputString[8] = ' ';  
outputString[9] = '\\0';
```

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 inputString including terminating zero

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

char array



Relationship between Arrays and Pointers

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

```
char word[10];  
char *cptr;
```

```
cptr = word; /* points to word[0] */  
           /* same as cptr = &word[0]; */
```

Difference:

Can change the contents of cptr, as in

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

(but "word" is like a constant and cannot be changed.)

Correspondence between Ptr and Array Notation

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

<code>cptr</code>	<code>word</code>	<code>&word[0]</code>
<code>(cptr + n)</code>	<code>word + n</code>	<code>&word[n]</code>
<code>*cptr</code>	<code>*word</code>	<code>word[0]</code>
<code>*(cptr + n)</code>	<code>*(word + n)</code>	<code>word[n]</code>

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;
```

Declaration with variable size

- Size of array must be known at compile time.

```
void SomeFunction(int num_elements) {  
    int temp[num_elements];  
    ...  
}
```

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 and char, both of which take up one word.
- If double (which takes up two words), we'd have to add **8** to find address of the 4th element.

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

```
double x[10];
```

allocates 20 words (2 per element)

```
double *y = x;
```

```
*(y + 3) = 13;
```

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

꼭 기억해야 할 것

- pointers are variables that contain addresses of variables
 - useful for returning multiple values from a function
 - `&var`: address of variable `var`
 - `*ptr`: the value of memory location pointed by `ptr`
- Array
 - a mechanism to group multiple elements of a homogeneous type
 - its elements allocated sequentially in memory
 - Example
 - `int a[5];` is a declaration of an integer array with 5 elements
 - `a[0]` refers to the 1st element of the array `a`
 - `a` refers to the address of `a[0]` (i.e., `&a[0]`)