C 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.

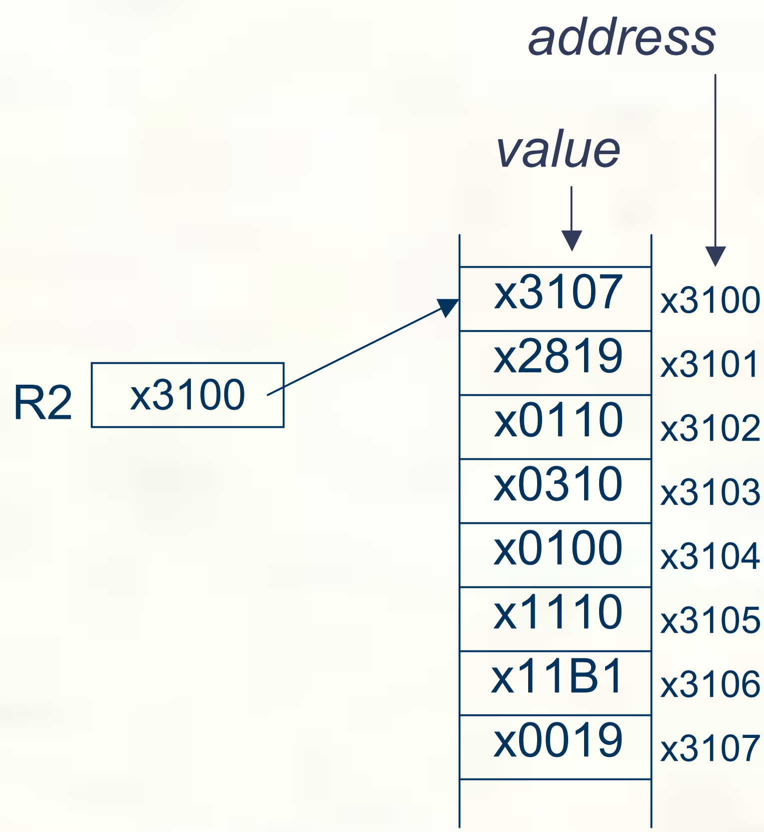
- Pointer
  - Address of a variable in memory
  - Allows us to indirectly access variables
    - in other words, we can talk about its *address* rather than its *value*
- Array
  - A list of values arranged sequentially in memory
  - Example: a list of telephone numbers
  - Expression `a[4]` refers to 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.

- 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.

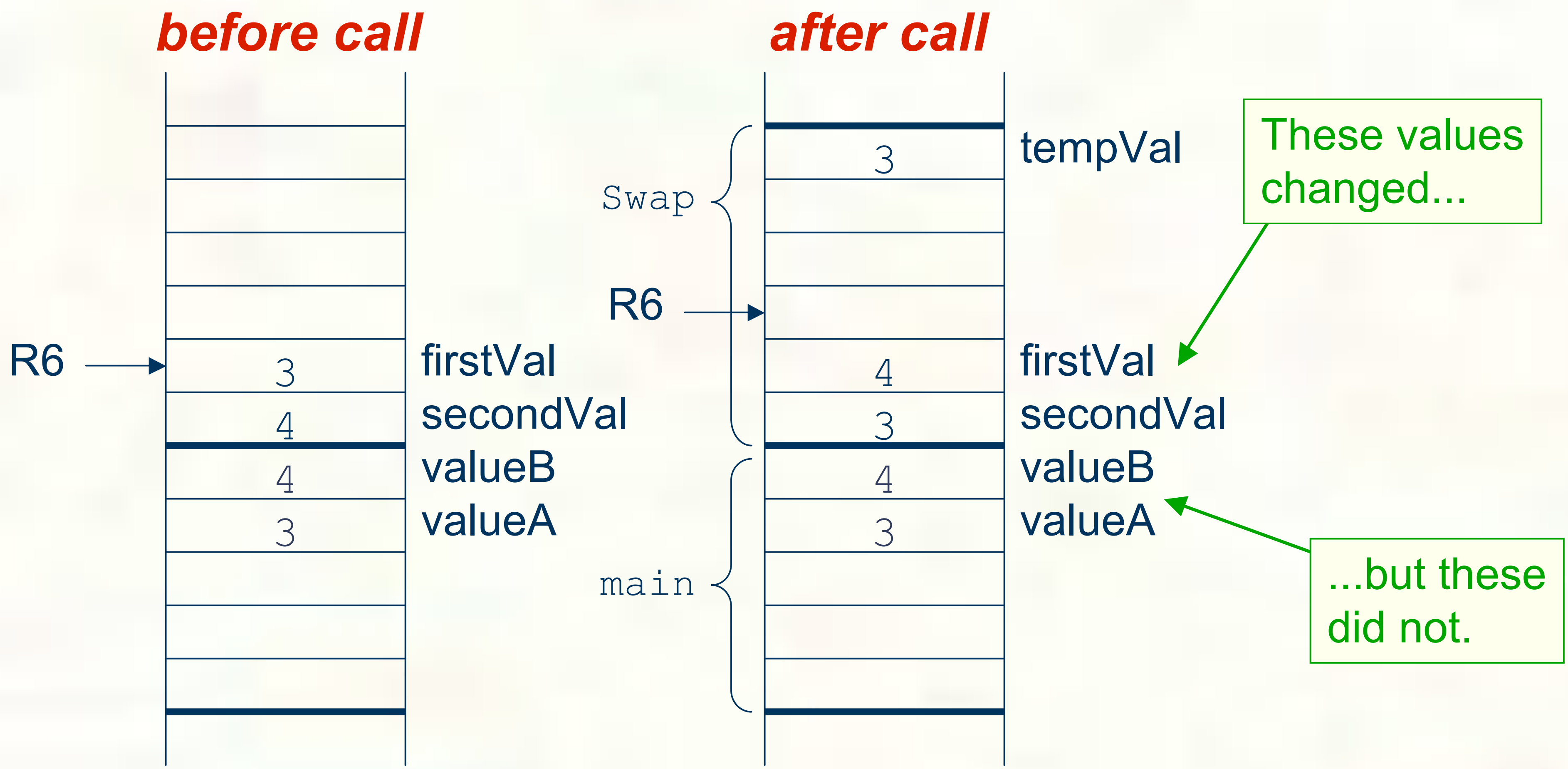


Another Need for Addresses

- 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



Swap needs <u>addresses</u> 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;
```

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

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 <u>pointers</u>. Caller passes <u>addresses</u> of variables that it wants function to change.

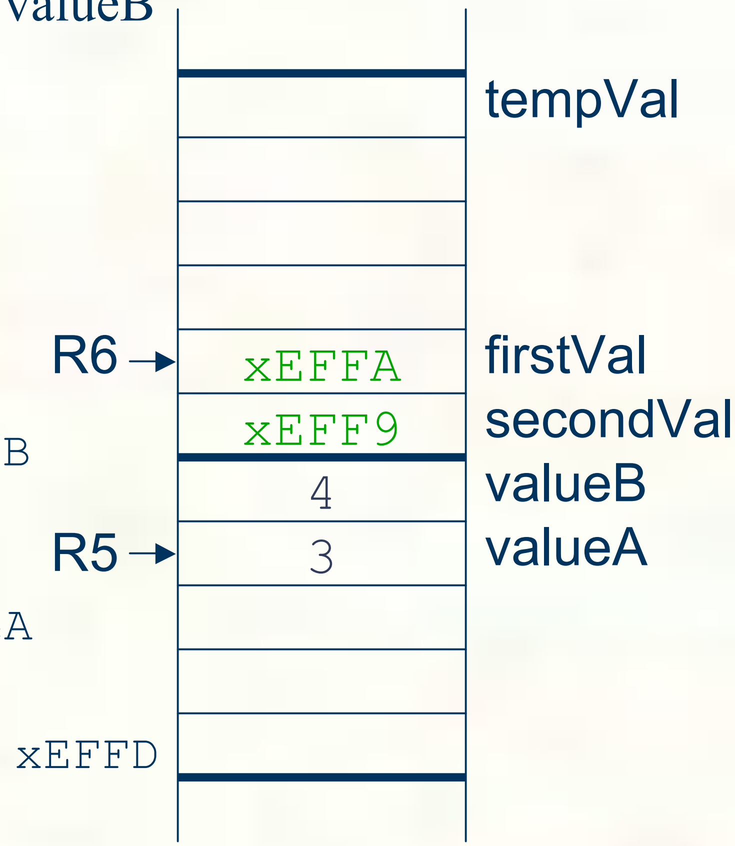
Passing Pointers to a Function

- main() wants to swap the values of valueA and valueB
- passes the addresses to NewSwap:

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

- Code for passing arguments:

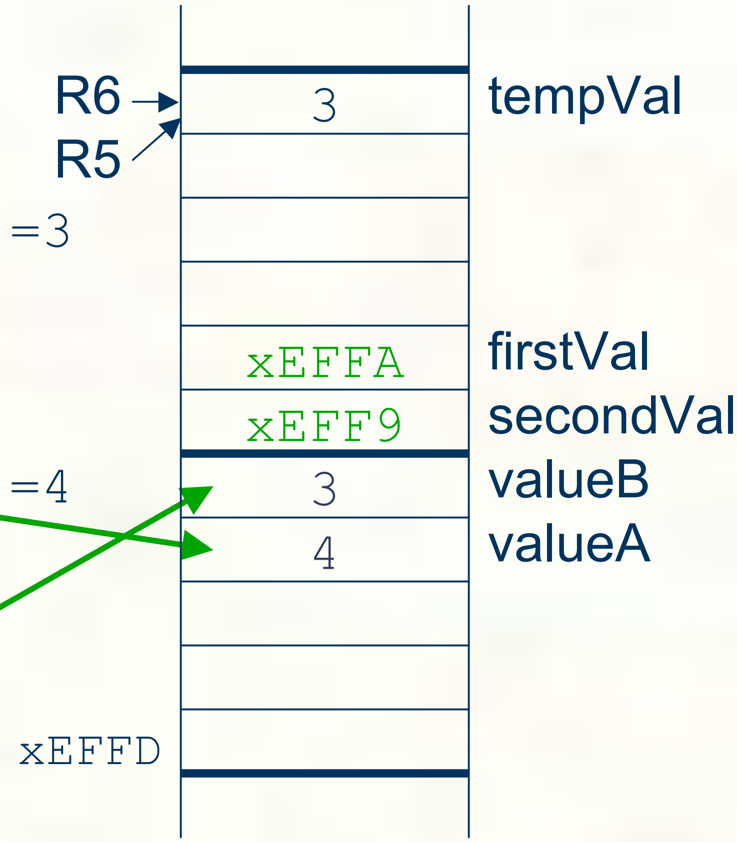
```
ADD R0, R5, #-1 ; addr of valueB
ADD R6, R6, #-1 ; push
STR R0, R6, #0
ADD R0, R5, #0  ; addr of valueA
ADD R6, R6, #-1 ; push
STR R0, R6, #0
```



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, #4 ; tempVal=3
; *firstVal = *secondVal;
LDR  R1, R5, #5 ; R1=xEFF9
LDR  R2, R1, #0 ; R1=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 value via pointer

      return status code as function result

- 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 *var;
type* var;
```

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

```
&var
```

- Must be applied to a memory object, such as a variable.
  In other words, `&3` is not allowed.
- Dereferencing
  Can be applied to any expression. All of these are legal:

`*var`	contents of mem loc pointed to by var
`**var`	contents of mem loc pointed to by memory location pointed to by var
`*3`	contents of memory location 3

Example using Pointers

- IntDivide performs both integer division and remainder, returning results 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, remainer; /* 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?

```
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

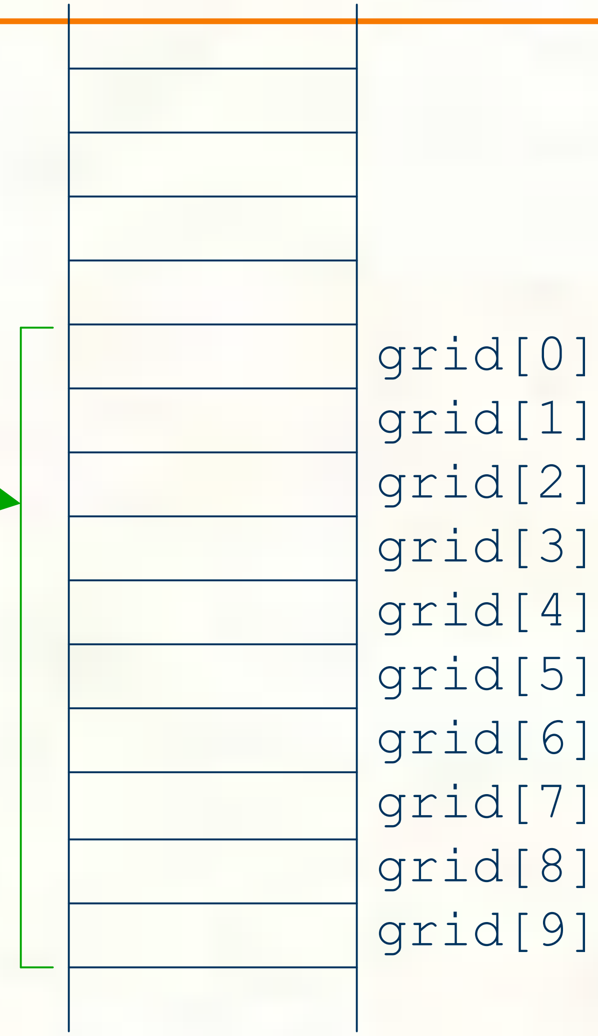
variable[index];

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

Array as a Local Variable

- Array elements are allocated as part of the activation record.

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

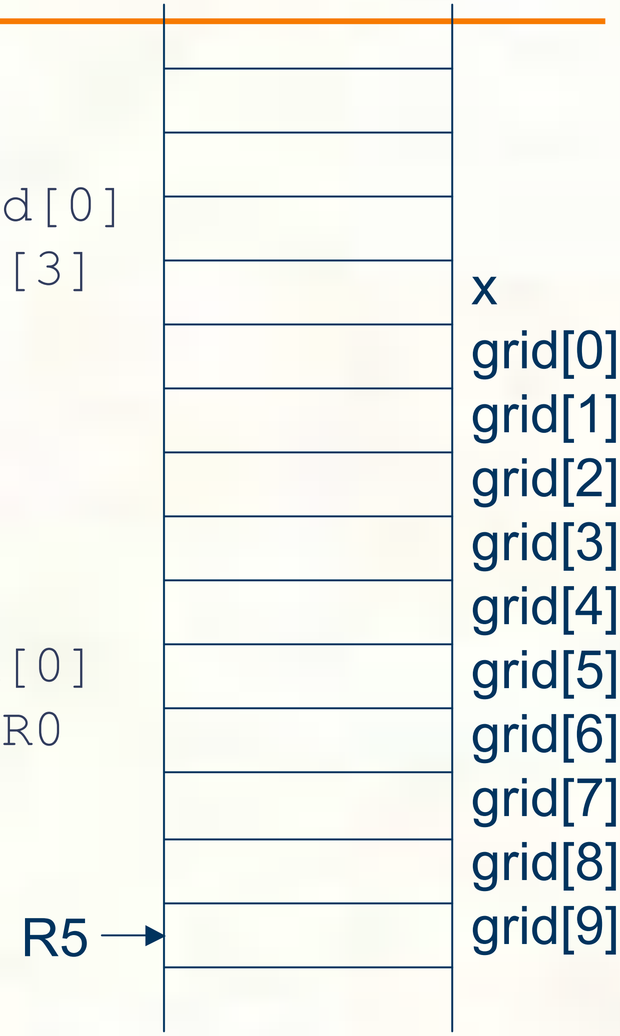


- First element (`grid[0]`) is at lowest address of allocated space.

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

LC-3 Code for Array References

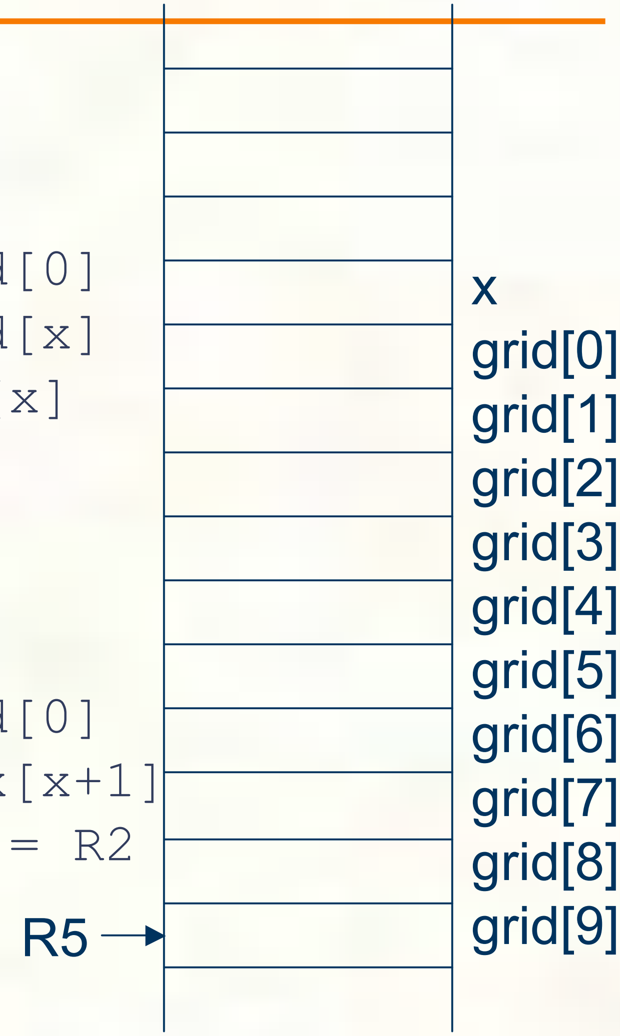
```
; x = grid[3] + 1
ADD R0, R5, #-9   ; R0 = &grid[0]
LDR R1, R0, #3    ; R1 = grid[3]
ADD R1, R1, #1    ; plus 1
STR R1, R5, #-10 ; x = R1
; grid[6] = 5;
AND R0, R0, #0
ADD R0, R0, #5  ; R0 = 5
ADD R1, R5, #-9 ; R1 = &grid[0]
STR R0, R1, #6  ; grid[6] = R0
```



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 = &grix[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
  - otherwise, would have to copy each element

```
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';
...
```

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);
```

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] */
```

- *Difference:*
  Can change the contents of cptr, as in
- ```
  cptr = cptr + 1;
  ```
- (The identifier "word" is not a variable.)
  ```

Ptr and Array Notation

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

`cptr`	`word`	`&word[0]`
`(cptr + n)`	`word + n`	`&word[n]`
`*cptr`	`*word`	`word[0]`
`*(cptr + n)`	`*(word + n)`	`word[n]`

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, 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) = 13;
```

allocates 20 words (2 per element)

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