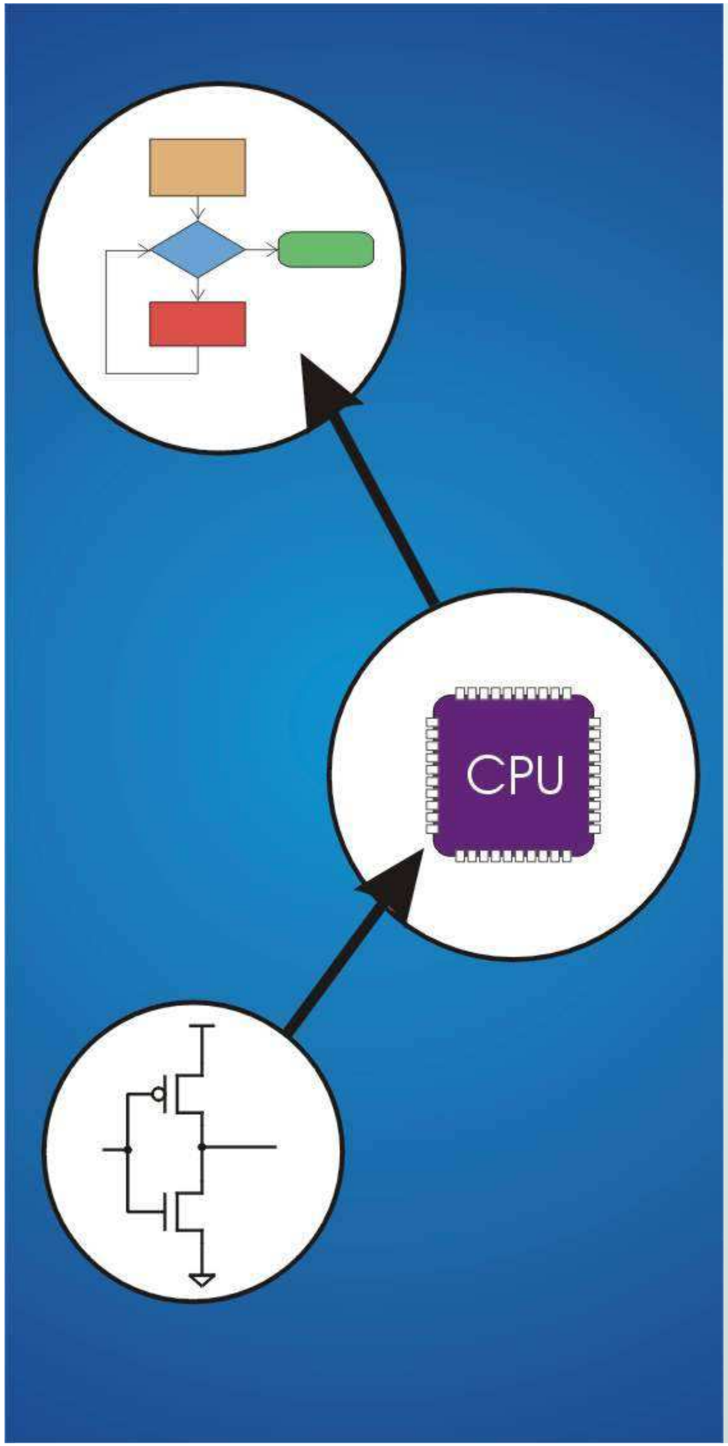

Chapter 16
Pointers and Arrays

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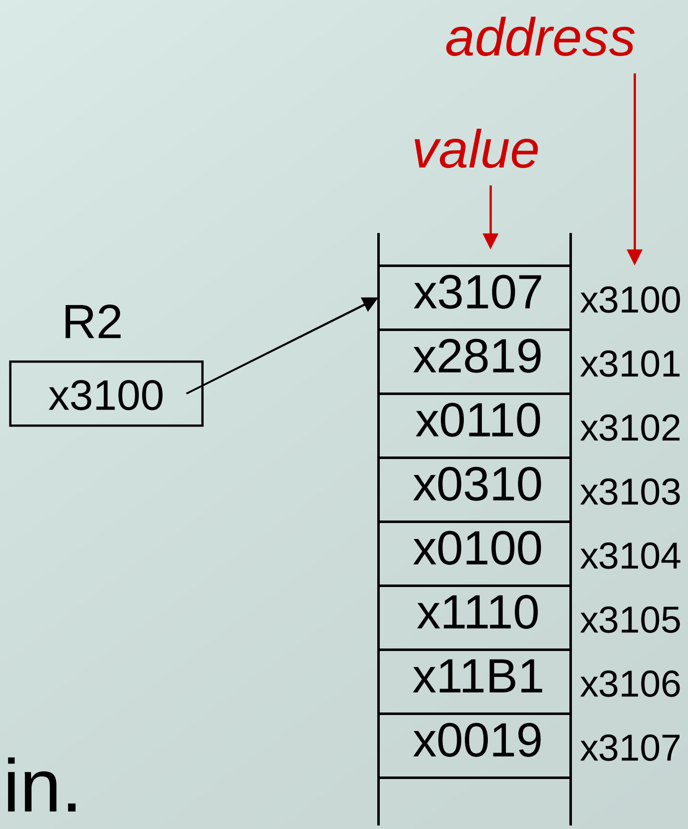
Pointers and Arrays

- We've seen examples of both 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.

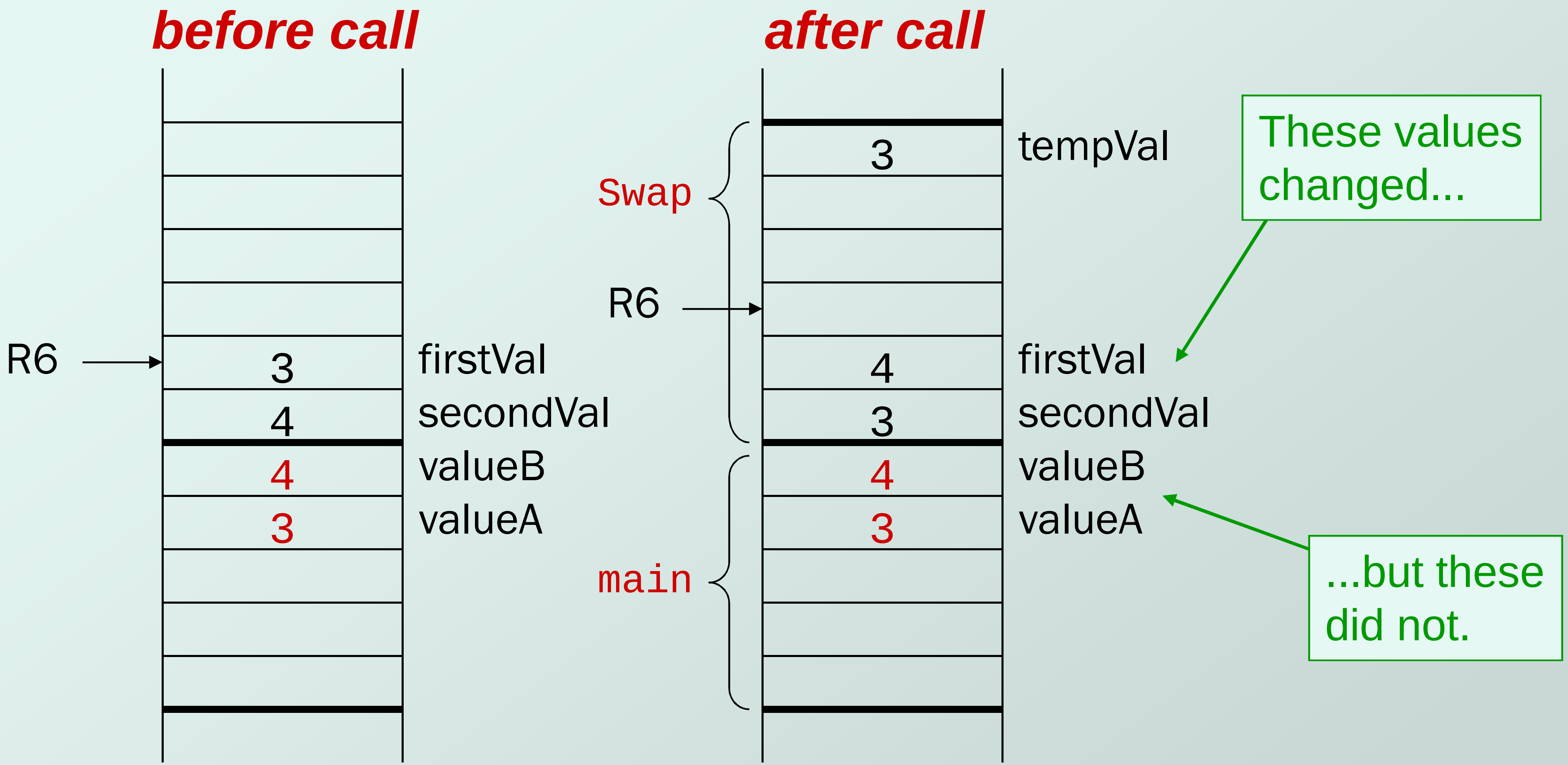


Another Need for Addresses

- 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 has explicit syntax for representing addresses – we can talk about and manipulate pointers as variables and in expressions.
  - Declaration

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

- A pointer in C points to a particular data type: **`int*`**, **`double*`**, **`char*`**, etc.
  - Operators

***p** -- returns the **value pointed by** p ("dereferencing")

&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 (&i)
    STR  R0,R5,#-1 ; store in ptr
; *ptr = *ptr + 1;
    LDR  R0,R5,#-1 ; R0 = mem[R5 – 1] (ptr)
    LDR  R1,R0,#0  ; load contents (*ptr)
    ADD  R1,R1,#1  ; *ptr + 1
    STR  R1,R0,#0  ; store contents (*ptr)
```

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.

```
To call:
NewSwap(&valueA, &valueB);
```

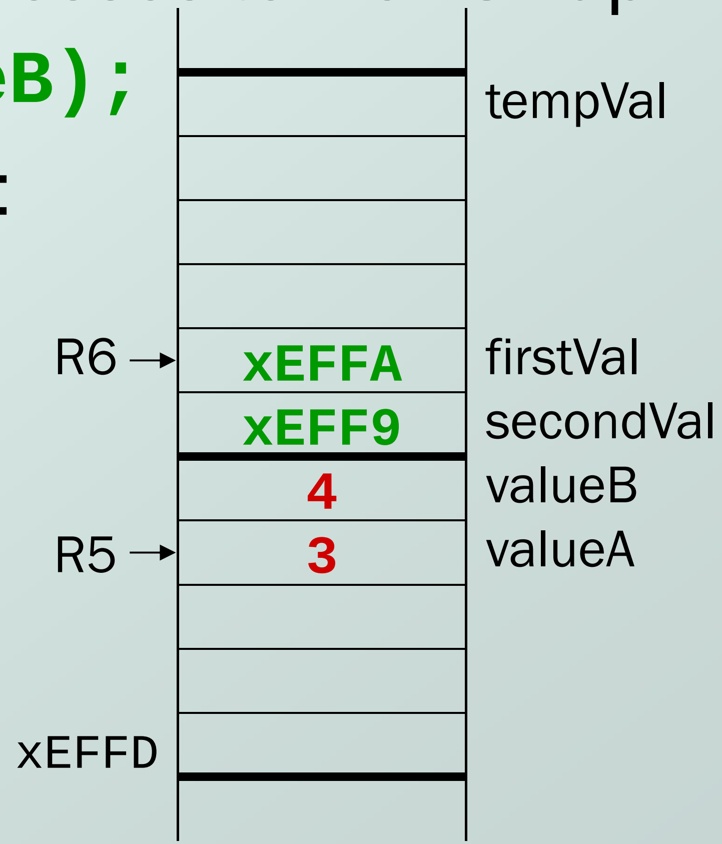
Passing Pointers to a Function

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

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

- Code for passing arguments:

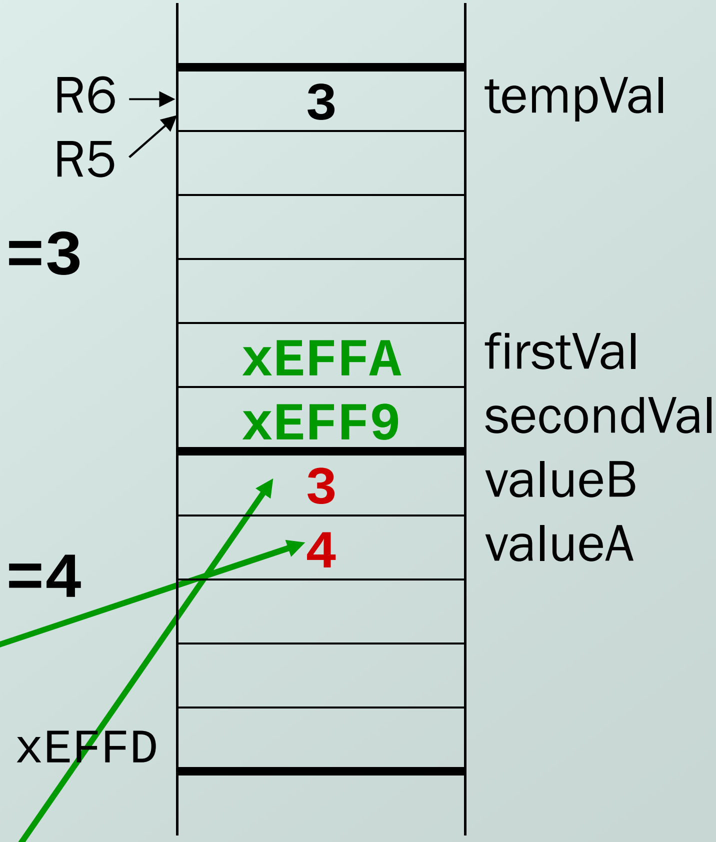
```
ADD R0,R5,#-1 ; &valueB
ADD R6,R6,#-1 ; push
STR R0,R6,#0  ;  it
ADD R0,R5,#0  ; &valueA
ADD R6,R6,#-1 ; push
STR R0,R6,#0  ;  it
```



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.
  - NULL =usually equals 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;` **or** `type* var;`

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

- Creating a pointer

  `&var`

  - Must be applied to a memory object, such as a variable (not &3)

- Dereferencing

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

```
*var // contents of memory pointed to by var
**var // contents of memory location pointed to
      // by memory location pointed to by var
```

Example using Pointers

- IntDivide performs both integer division and remainder, returning results via pointers.
  - Returns –1 if divide by zero, else 0

```
int IntDivide(int x, int y, int *quoPtr, int *remPtr);
main()
{
    int dividend, divisor;  /* numbers for divide op */
    int quotient, remainer; /* results */
    int error;
    /* ... Input code 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];
```

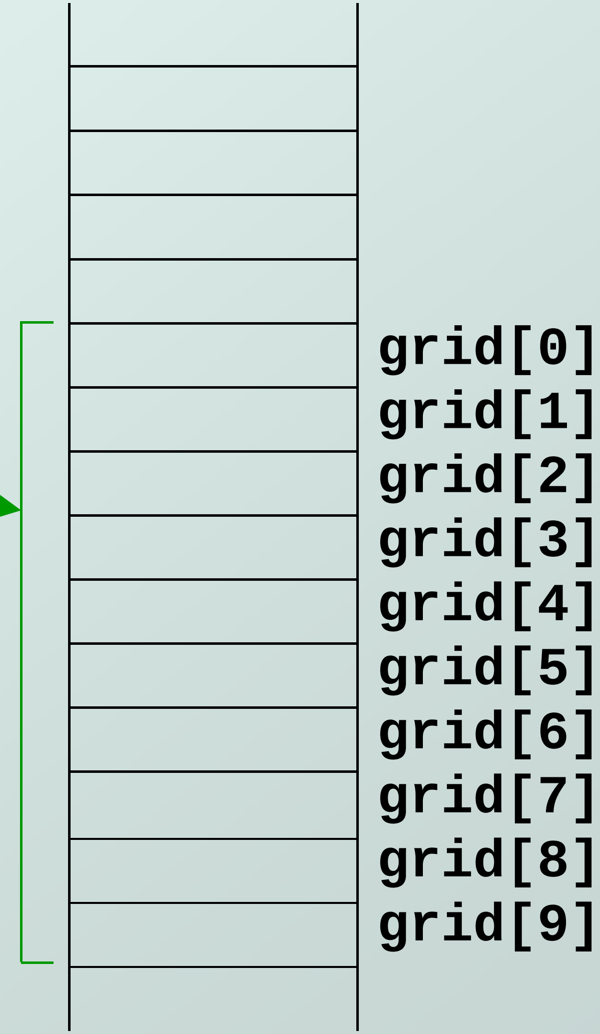
i-th element of array (starting with zero); no limit checking at compile-time or run-time

Array as a Local Variable

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

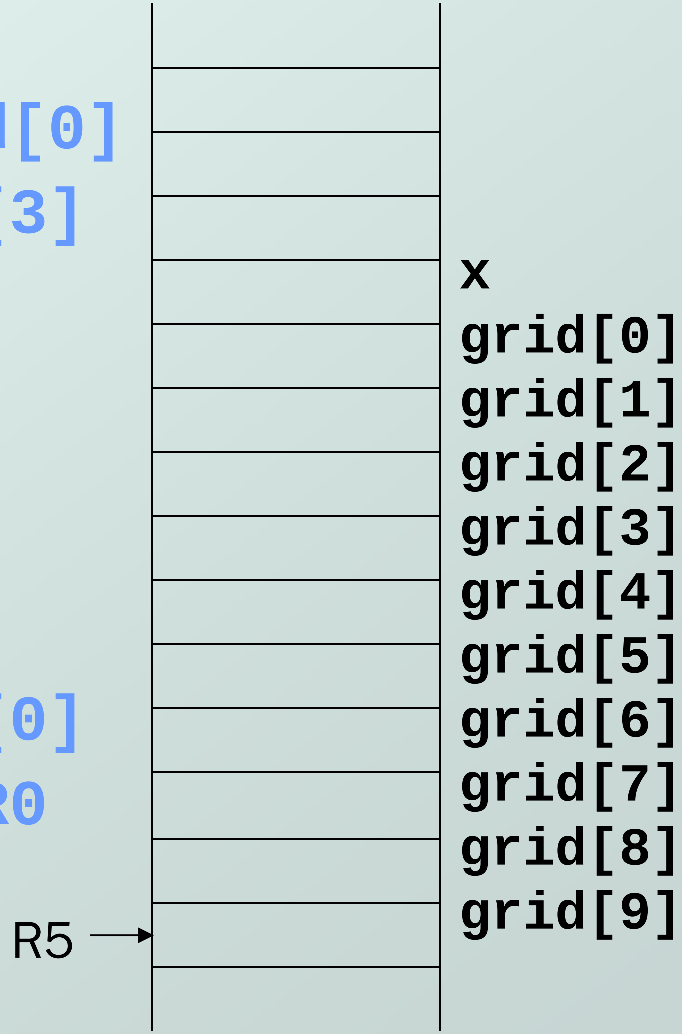
  `int grid[10];`

- First element (**`grid[0]`**) is at lowest address of allocated space.
- If `grid` is first variable allocated, then R5 will point to **`grid[9]`**.



LC-3 Code for Array References

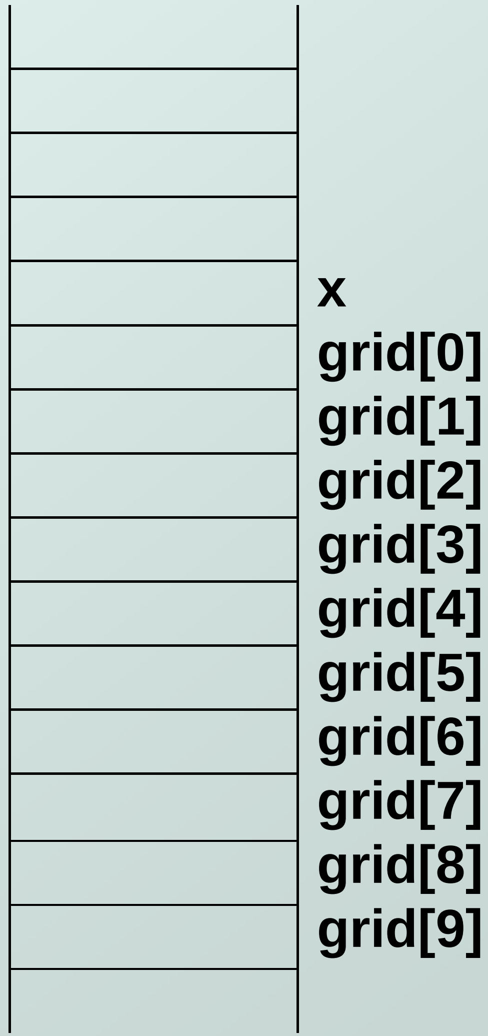
```
; x = grid[3] + 1
  ADD R0,R5,#-9  ; R0 = &grid[0]
  LDR R1,R0,#3   ; R1 = grid[3]
  ADD R1,R1,#1   ; plus 1
  STR R1,R5,#-10 ; x = R1
; grid[6] = 5;
  AND R0,R0,#0
  ADD R0,R0,#5  ; R0 = 5
  ADD R1,R5,#-9 ; R1 = &grid[0]
  STR R0,R1,#6  ; grid[6] = R0
```



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 pointer
  - 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 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);
```

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] */
```

- *Difference:*
  - Can change the contents of cptr, as in

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

- Why? Because the identifier "word" is not a variable.

Correspondence between Ptr and Array Notation

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

- 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]`

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 i;
int array[10];
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
  - Our LC-3 code has been assuming a 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 (how about byte addressable systems?)
- C does size calculations under the covers, depending on size of item being pointed to:

```
double x[10];
double *y = x;
    *(y + 3) = 13;
```

double x[10]; ← allocates 20 words (2 per element)

*(y + 3) = 13; ← **same as x[3] -- base address plus 6**