

Chapter 16 Pointers and Arrays

Original slides from Gregory Byrd, North
Carolina State University
Modified slides by C. Wilcox, S. Rajopadhye
Colorado State University

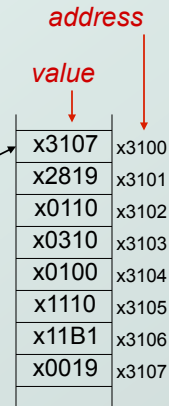
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Pointers and Arrays

- 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
 - 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 R2 x3100
 - 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;
}
```


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 = 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 pointers. Caller passes addresses of variables that it wants function to change.

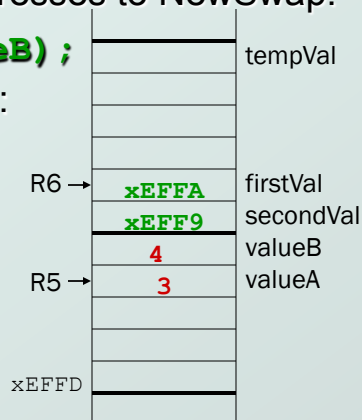
Passing Pointers to a Function

- 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
ADD R0,R5,#0 ; &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[xEFA]=3
```

```
STR R1,R5,#0; tempVal=3
```

```
; *firstVal = *secondVal;
```

```
LDR R1,R5,#5 ; R1=xEFF9
```

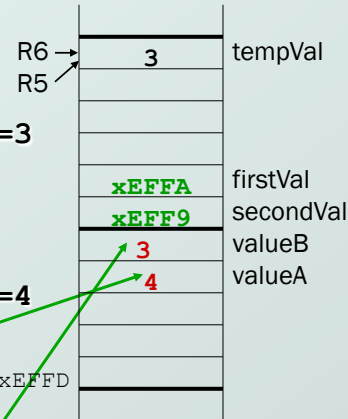
```
LDR R2,R1,#0 ; R2=M[xEFF9]=4
```

```
STR R2,R0,#0 ; M[xEFA]=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, remainder; /* 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

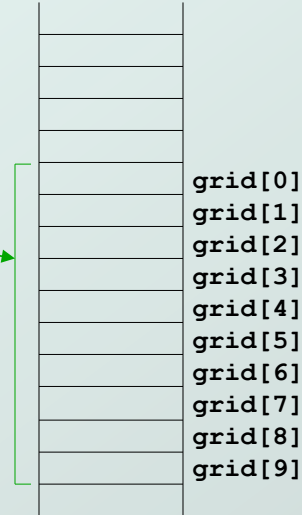
- **Array Reference**

```
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]`.

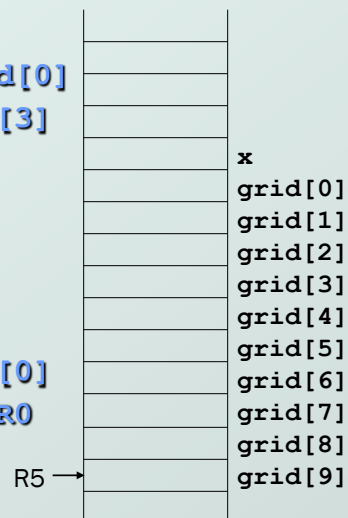


LC-3 Code for Array References

```

; 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
    
```



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

- 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**

- 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]; ← allocates 20 words (2 per element)
double *y = x;
*(y + 3) = 13; ← same as x[3] -- base address plus 6
```