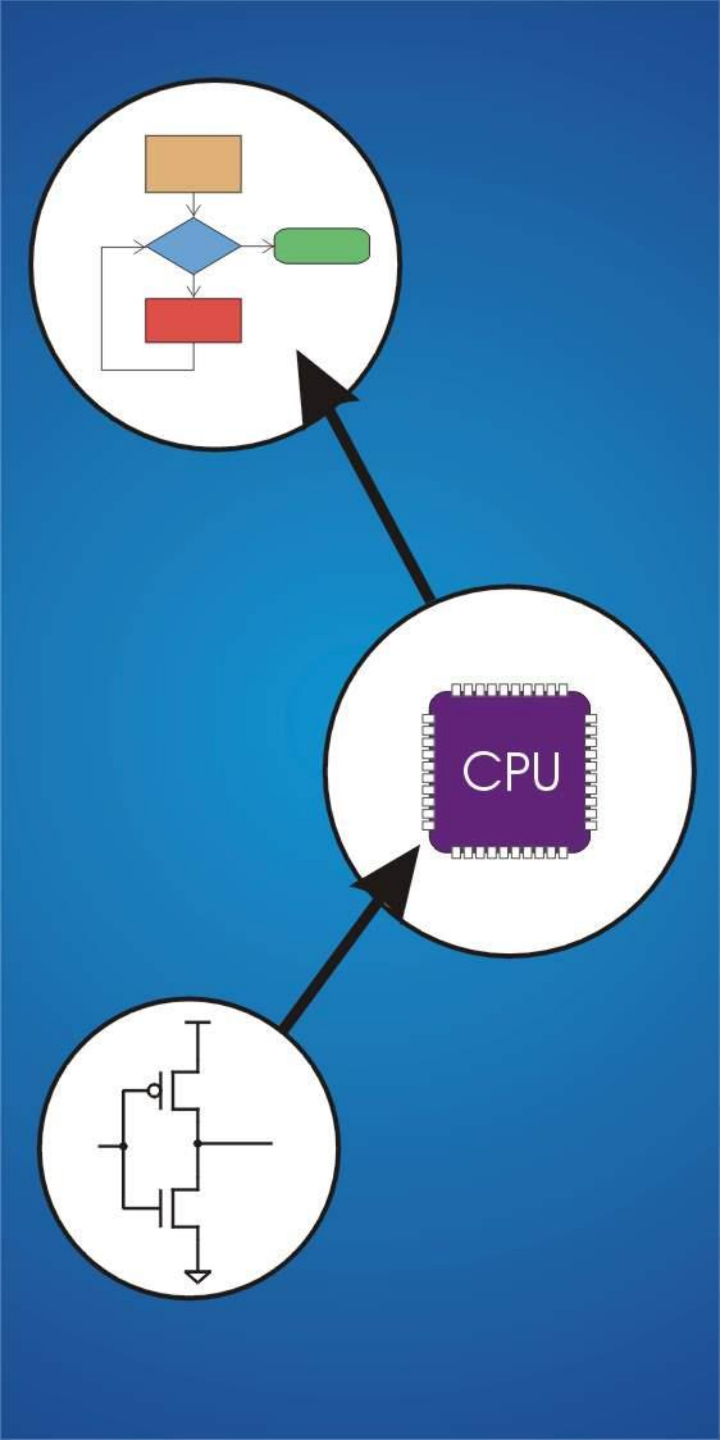


Chapter 16
Pointers and Arrays

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 <u>indirectly</u> access variables**
  - **in other words, we can talk about its *address* rather than its *value***

Array

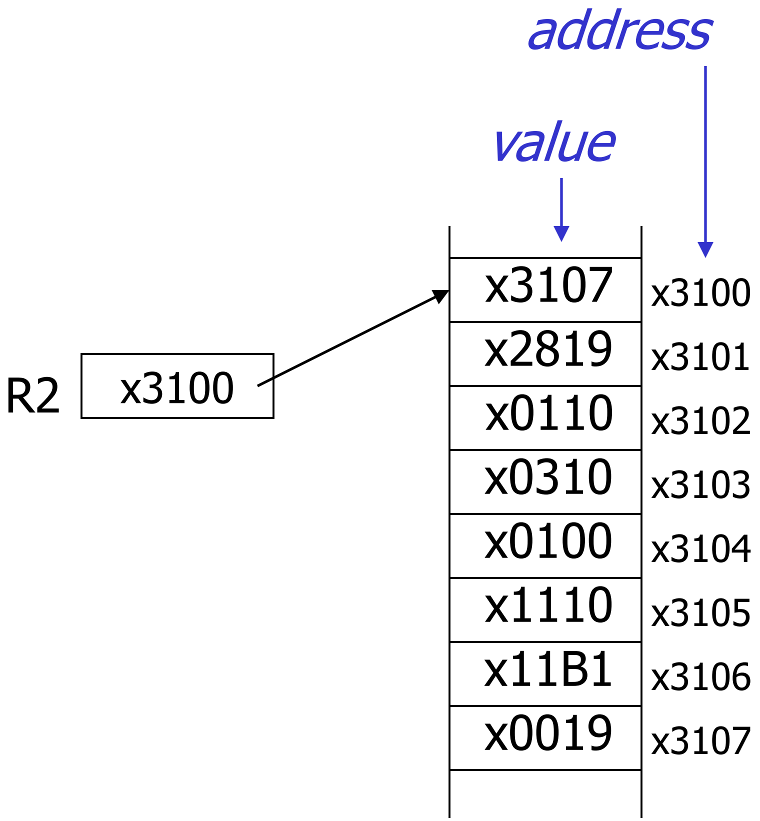
- **A list of values arranged sequentially in memory**
- **Example: a list of telephone numbers**
- **Expression `a[4]` refers to the 5th element of the array `a`**

Address vs. Value

Sometimes we want to deal with the <u>address</u> of a memory location, rather than the <u>value</u> 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;
}
```

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

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.

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

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

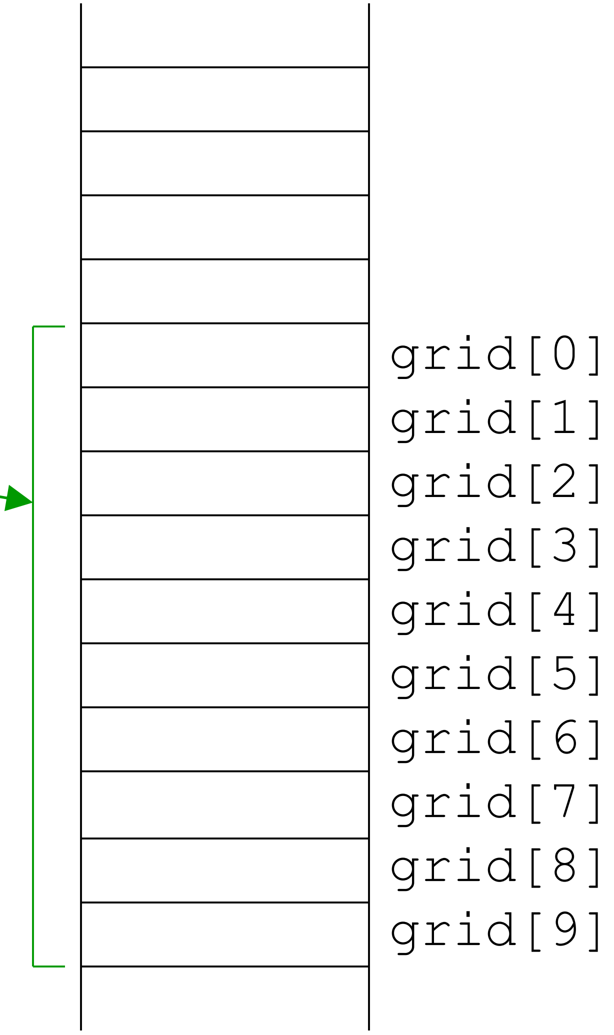
```
variable[index];
```

i-th element of array (starting with zero); 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]`.

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);
```

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;
```

(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:

`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 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;
```

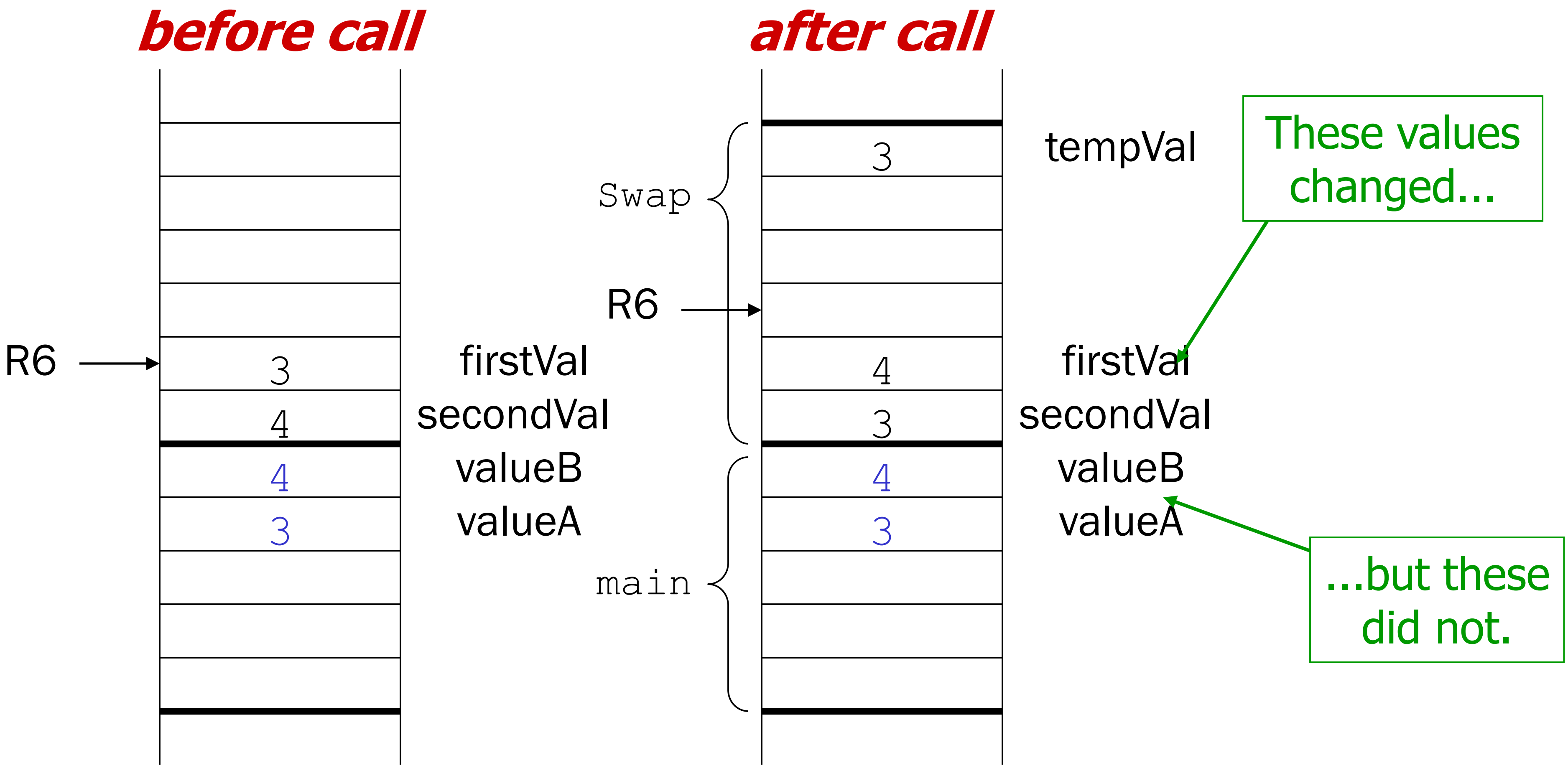
allocates 20 words (2 per element)

same as x[3] -- base address plus 6 (3*sizeof(double)

Skip the following slides

We will come back to these

Executing the Swap Function



Swap needs <u>addresses</u> of variables outside its own activation record.

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
```

Passing Pointers to a Function

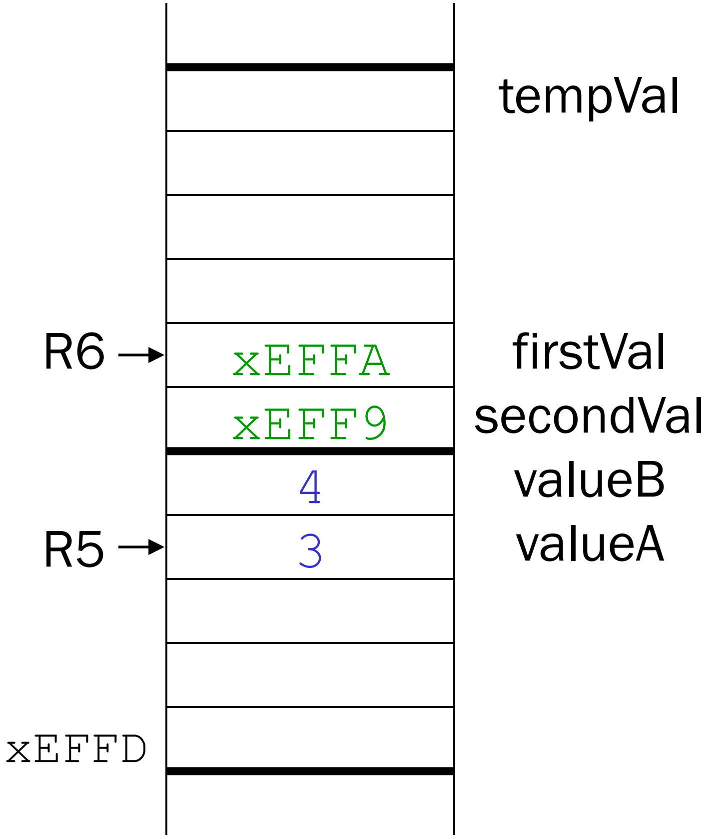
main() wants to swap the values of valueA and valueB

passes the addresses to NewSwap:

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

Code for passing arguments:

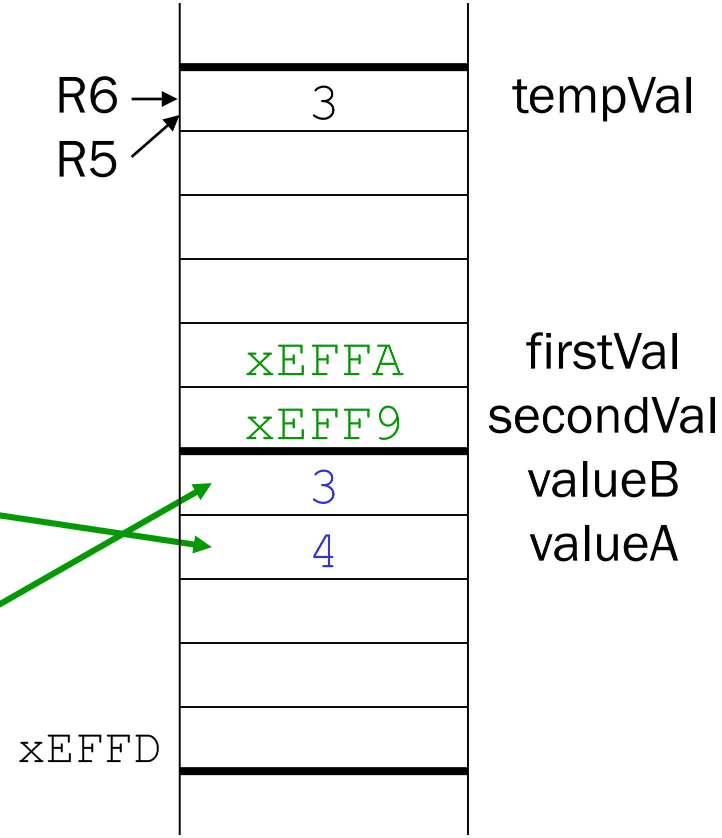
```
ADD R0, R5, #-1 ; addr of valueB
ADD R6, R6, #-1 ; push
STR R0, R6, #0
ADD R0, R5, #0  ; addr of valueA
ADD R6, R6, #-1 ; push
STR R0, R6, #0
```



Code Using Pointers

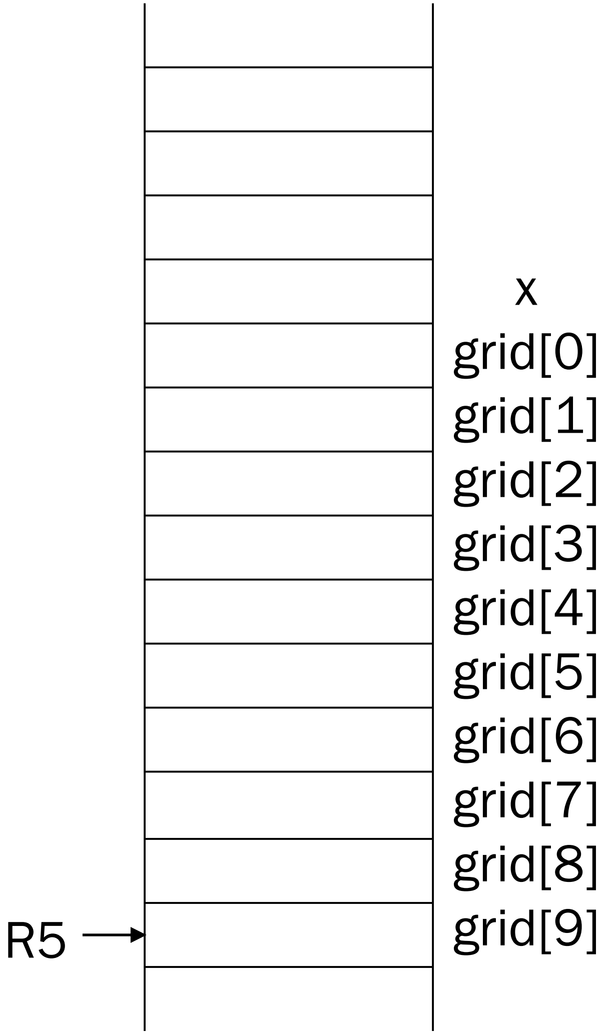
Inside the NewSwap routine

```
; 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
```



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
```