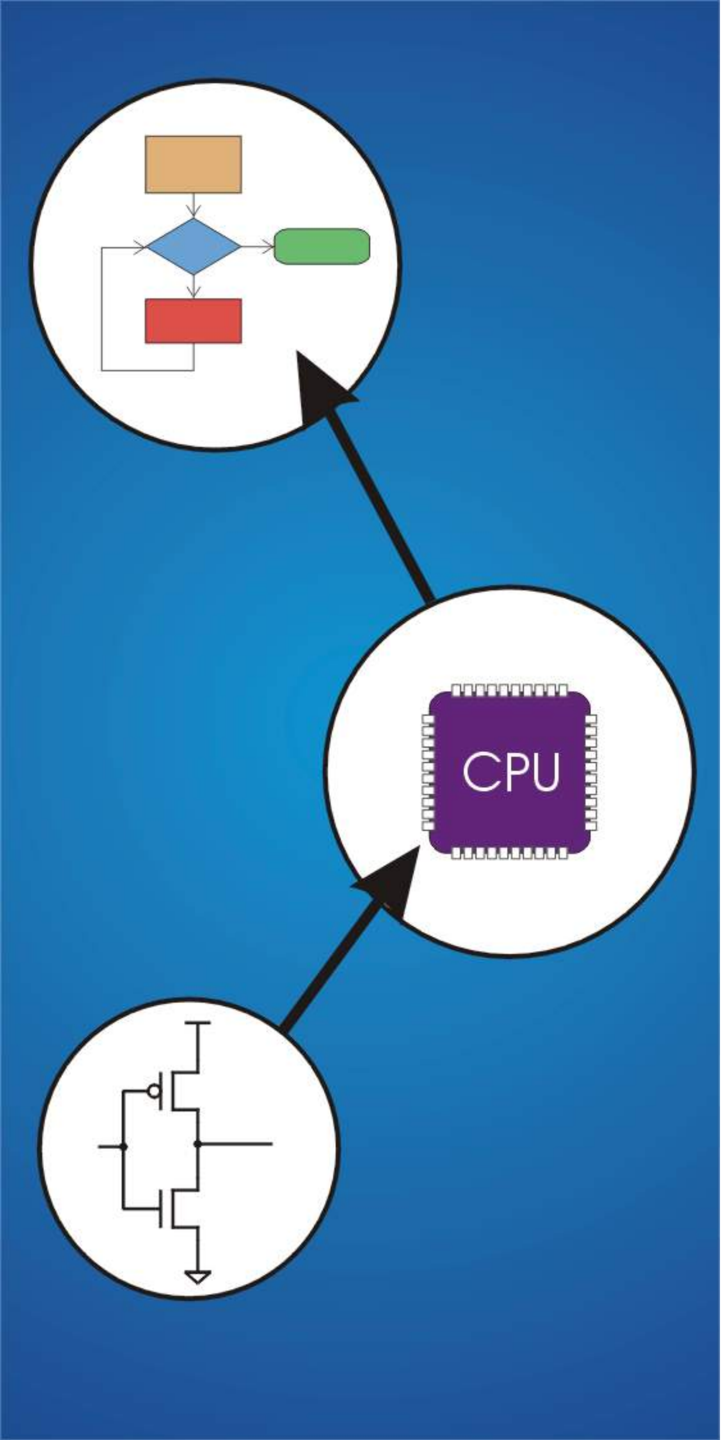


Chapter 16
Pointers and Arrays

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`**

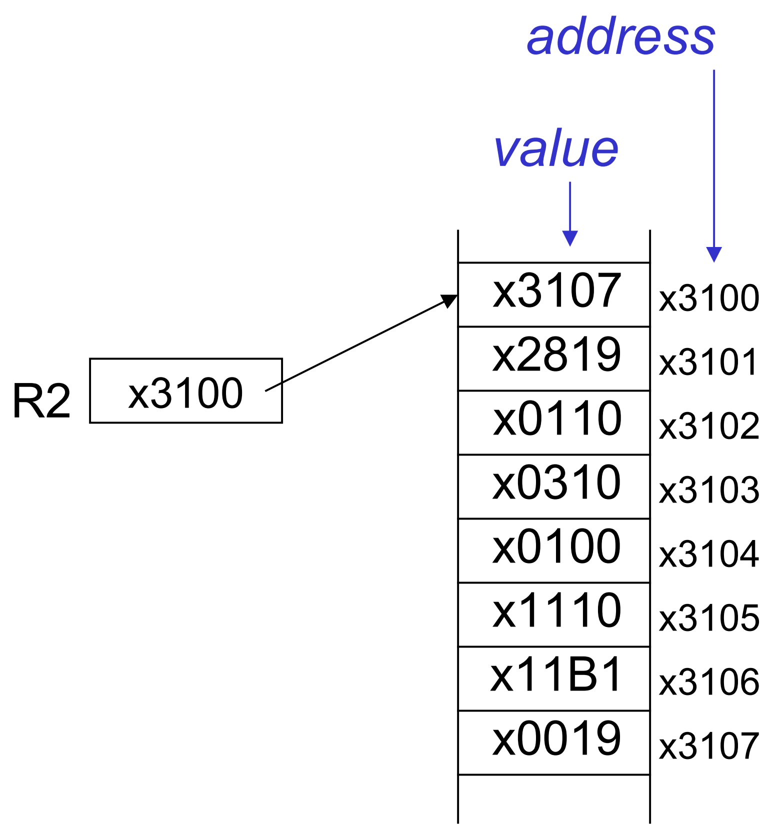
Address vs. Value

Sometimes we want to deal with the 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.

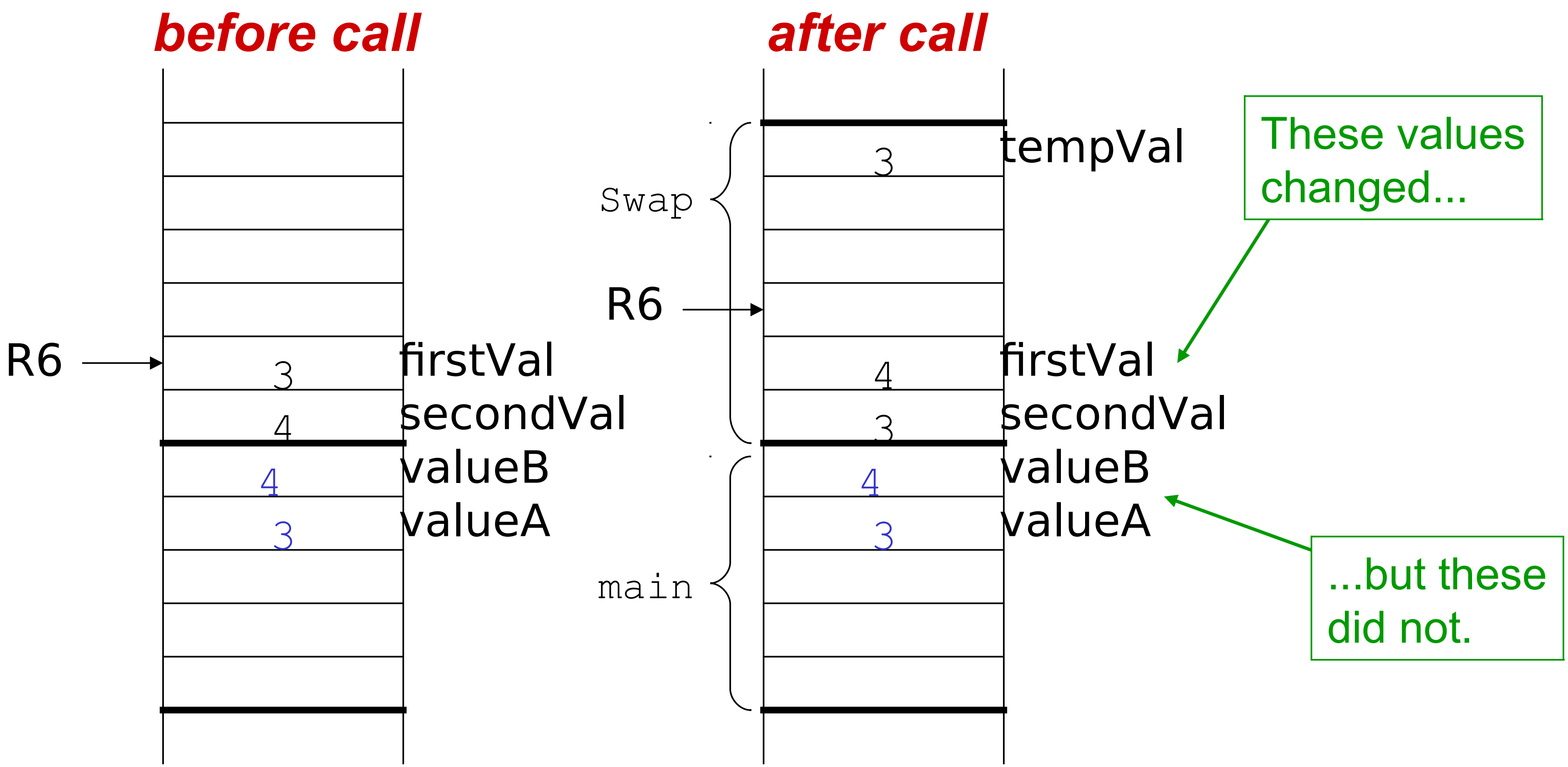


Another Need for Addresses

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

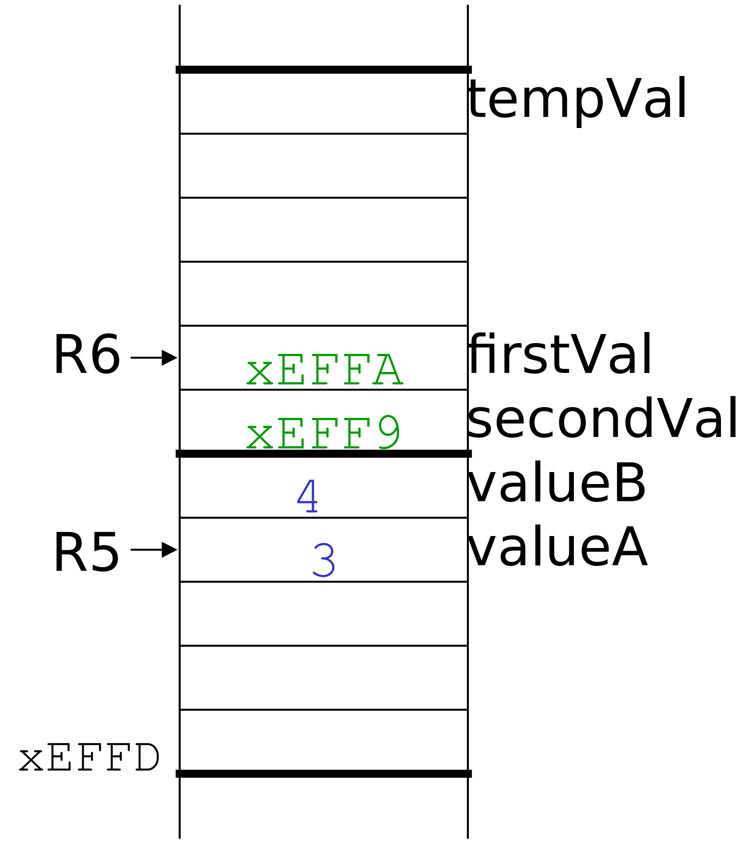
main() wants to swap the values of valueA and valueB

passes the addresses to NewSwap:

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

Code for passing arguments:

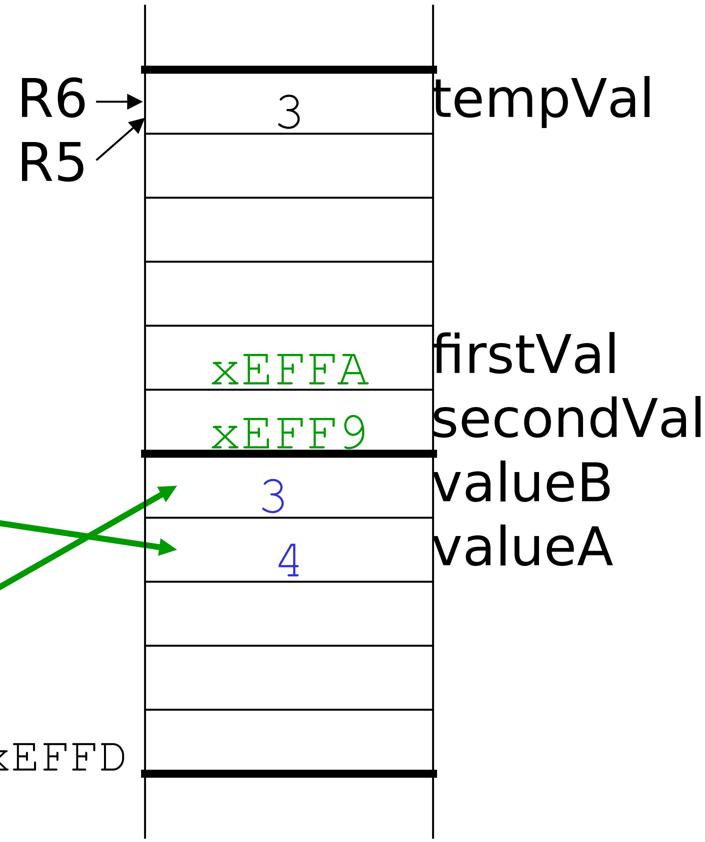
```
ADD R0, R5, #-1 ; addr of valueB
ADD R6, R6, #-1 ; push
STR R0, R6, #0
ADD R0, R5, #0  ; addr of valueA
ADD R6, R6, #-1 ; push
STR R0, R6, #0
```



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, 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?

```
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

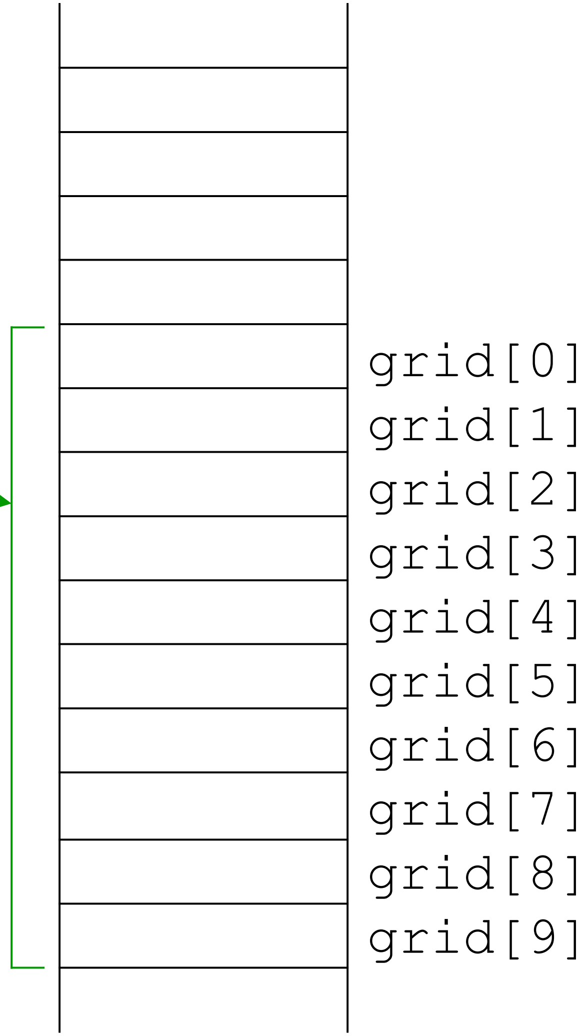
```
variable[index];
```

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];
```

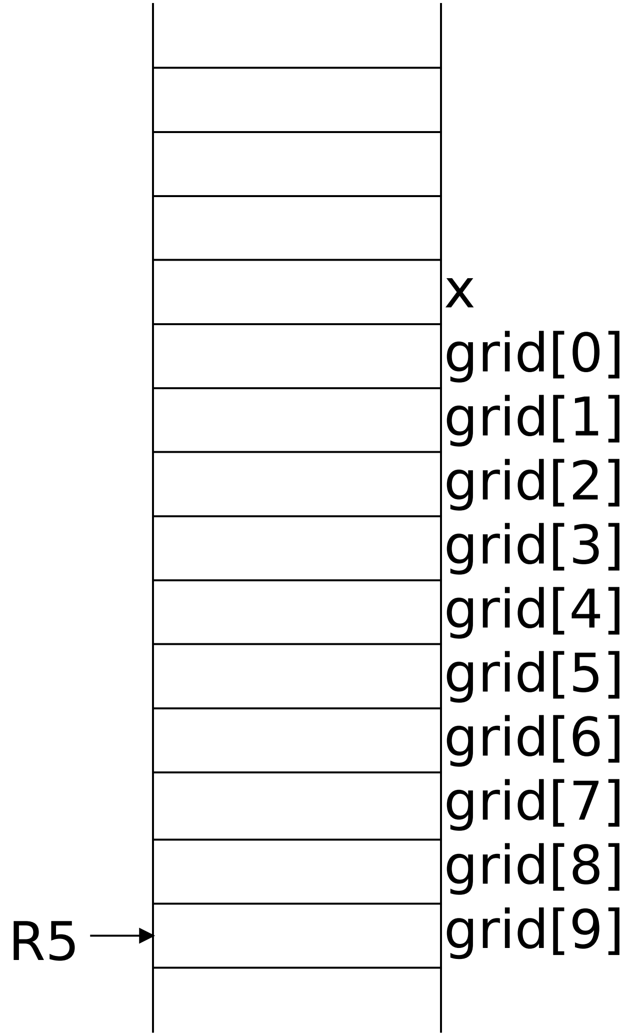


First element (`grid[0]`) is at lowest address of allocated space.

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

LC-3 Code for Array References

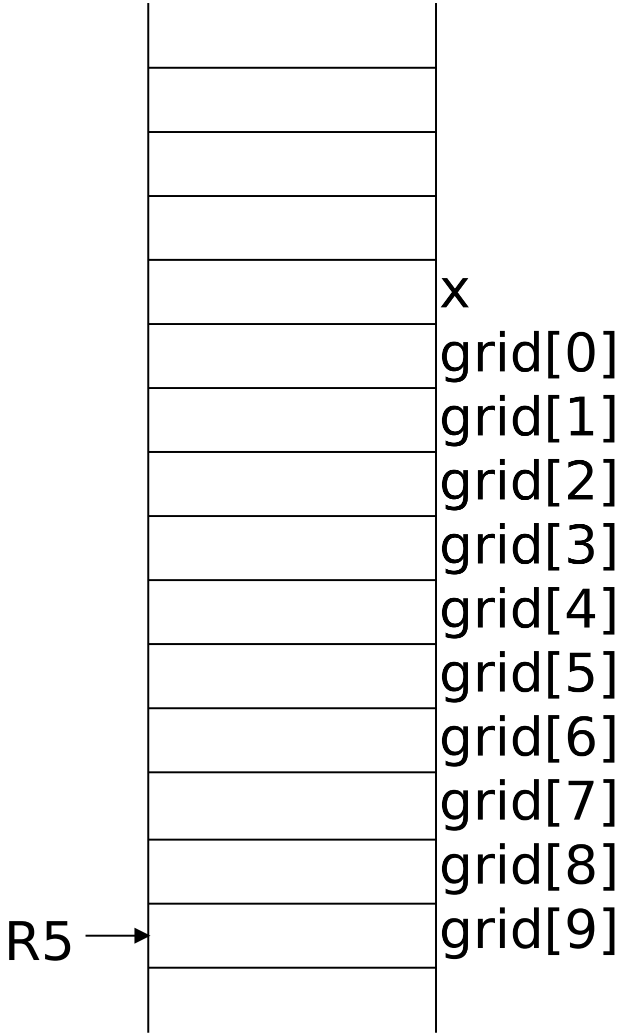
```
; x = grid[3] + 1
   ADD R0, R5, #-9   ; R0 = &grid[0]
   LDR R1, R0, #3    ; R1 = grid[3]
   ADD R1, R1, #1    ; plus 1
   STR R1, R5, #-10  ; x = R1
; grid[6] = 5;
   AND R0, R0, #0
   ADD R0, R0, #5   ; R0 = 5
   ADD R1, R5, #-9 ; R1 = &grid[0]
   STR R0, R1, #6   ; grid[6] = R0
```



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 = &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);
```

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