ECE 220

Lecture x000A - 09/30

Slides based on material originally by: Yuting Chen & Thomas Moon

Recap

- Recap:
  - Introduction to pointers & arrays, `sizeof` function, etc.
  - Briefly touched pointer/array duality
  - Writing equivalent LC3 for pointer dereferencing etc.
- Today
  - Wrap up pointer/array duality
  - Strings & multidimensional arrays
  - Problem solving examples

Lesson objectives

- Understand pointer/array duality as well as differences
- Implement lowering C code involving arrays to LC3 assembly
- Understand strings as character arrays and difference from string literals
- Avoid common pitfalls with string parsing
- Understand row-major indexing for higher-dimensional arrays

Recap

Last time we wrote this function together in class.

```c
#include <stdio.h>

int my_first_sum(int arr[]){
  int sum=0, i=0;
  for (i=0; i<5; i++)
    sum += arr[i];
  return sum;
}

int main(void){
  int i, arr[5];
  for (i=0; i<5; i++){
    printf("Enter an integer:\t");
    scanf("%d", &arr[i]);
  }
  printf("\nThe sum is %d", my_first_sum(arr));
}
```

Recap

How did we let the compiler know `my_first_sum` takes an array of integers as a parameter?

```c
#include <stdio.h>

int my_first_sum(int arr[]){
  int sum=0, i=0;
  for (i=0; i<5; i++)
    sum += arr[i];
  return sum;
}

int main(void){
  int i, arr[5];
  for (i=0; i<5; i++){
    printf("Enter an integer:\t");
    scanf("%d", &arr[i]);
  }
  printf("\nThe sum is %d", my_first_sum(arr));
}
```

Recap

How did we pass the parameter `arr` to the function `my_first_sum` ?

```c
#include <stdio.h>

int my_first_sum(int arr[]){
  int sum=0, i=0;
  for (i=0; i<5; i++)
    sum += arr[i];
  return sum;
}

int main(void){
  int i, arr[5];
  for (i=0; i<5; i++){
    printf("Enter an integer:\t");
    scanf("%d", &arr[i]);
  }
  printf("\nThe sum is %d", my_first_sum(arr));
}
```

Fact: The name of the array is *pointer* to the array!

Pointer/array duality

- In fact `arr[3]` is syntactic sugar for `*(arr + 3)` !!

```
int my_third_sum(int *arr){
  int i, sum=0;
  for (i=0; i<5; i++)
    sum += *(arr + i);
  return sum;
}
```

would also work just fine!

Dualities: each row of the table contains equivalent expressions

```
char arr[10];
 char *cptr;
 cptr = arr;
```

Pointer arithmetic	Pointer/Array	Array notation

Pointers - subtle points

- Is there a difference between `cptr` and `arr` in the below?

```
char arr[10];
char *cptr;
cptr = arr;
```

`cptr` is defined as a variable. The compiler allows it to be redefined.

- Try doing:

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

`arr` without the `[]` *decays* to a pointer but once declared is not assignable *sans* subscript.

Pointers - subtle points

- What is the difference between `arrp`, `arrpw` in the code snippet on the right?
- **Hint**: Consider the output.

```c
#include <stdio.h>

int main(){
    int *arrp;
    int (*arrpw)[5];
    int arr[5]={5,2,3,1,4};
    arrp = arr;
    arrpw = &arr;

    printf("arrp= %p, arrpw= %p\n", arrp, arrpw);
    arrp++;
    arrpw++;
    printf("arrp= %p, arrpw= %p\n", arrp, arrpw);
}
```

Pointers - subtle points

- What is the difference between `arrpw, parr` in the code snippet on the right?

```c
#include <stdio.h>

int main(void){
  int arr[5] = {1, 2, 3, 4, 5};
  int (*arrpw)[5] ;
  int *parr[5];

  arrpw = &arr;

  for (int i=0; i<5; i++){
    printf("*(*arrpw + %d): %d\n", i, *(*arrpw + i));
    printf("*parr[%d]: %d\n", i, *parr[i]);
  }
}
```

Same as before.

`parr` is now an *array* of five pointers.

More bewares …

- Pointers can be used to modify *static* variables defined inside functions.

```c
#include <stdio.h>

int *printx(void){
    static int x = 0;
    printf("value of x is %d \n",x++);
    return (&x);
}

int main(){
    int *x_ptr;
    x_ptr = printx();
    x_ptr = printx();
    *x_ptr = (*x_ptr) + 1;
    printx();
}
```

- Actually, pointers can also modify `const` variables.

```c
int main(void){
    const int var = 10;
    int *ptr = &var;

    *ptr = 12;
    printf("var = %d\n", var);
}
```

Yes there are things called `const` pointers - but we will only go there when we have to.

Summary: pointers & arrays

- Pointer
  - Stores the address of a variable in memory
  - Allows us to indirectly access/change variables
- Arrays
  - A list of values arranged sequentially in memory
  - Array name without index is the same as pointer to the array
  - Therefore in C, all arrays are ***passed by reference,*** i.e., if you change array passed to a function, change will be reflected outside!

Using arrays

- When using arrays we need to know the size or *dimensions* of the arrays.

- **Question:** Write a C *function* that sums an array of integers of given length n.

- Any loops in the function will need to know the size of the array to correctly terminate. Two common strategies:

  - Define the length as a global variable.

  - Write the *function* so that it accepts the array length as a *parameter*.

Using arrays

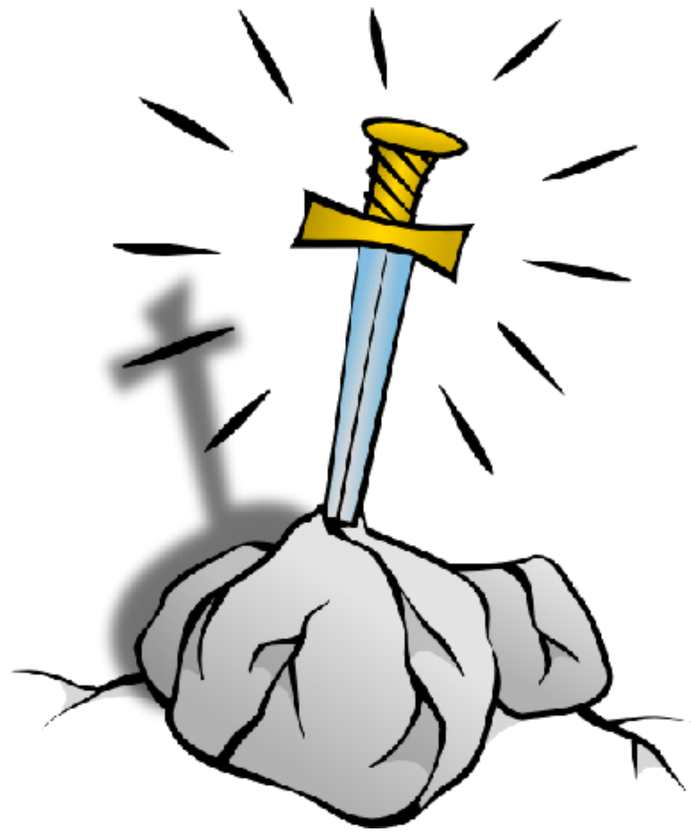
- When using arrays we need to know the size or *dimensions* of the arrays.
- **Question:** Write a C *function* that sums an array of integers of given length n.

```c
# include<stdio.h>

int any_sum(int arr[], int arr_len){
   int i, sum = 0;
   for (i=0; i < arr_len; i++)
      sum += arr[i];
   return sum;
}

int main(void){
   int arr1[] = {1, 2, 3, 4, 5};
   int arr2[] = {1, 2, 3, 4, 5, 6, 7, 8, 9};

   printf("sum(arr1): %d\n", any_sum(arr1, 5));
   printf("sum(arr2): %d\n", any_sum(arr2, 9));
}
```

Using arrays

- **Challenge:** Can the function be modified so `any_sum` can determine the size of the array *itself* (without passing in the value)?

Definitely let me know if you find a way. 😉

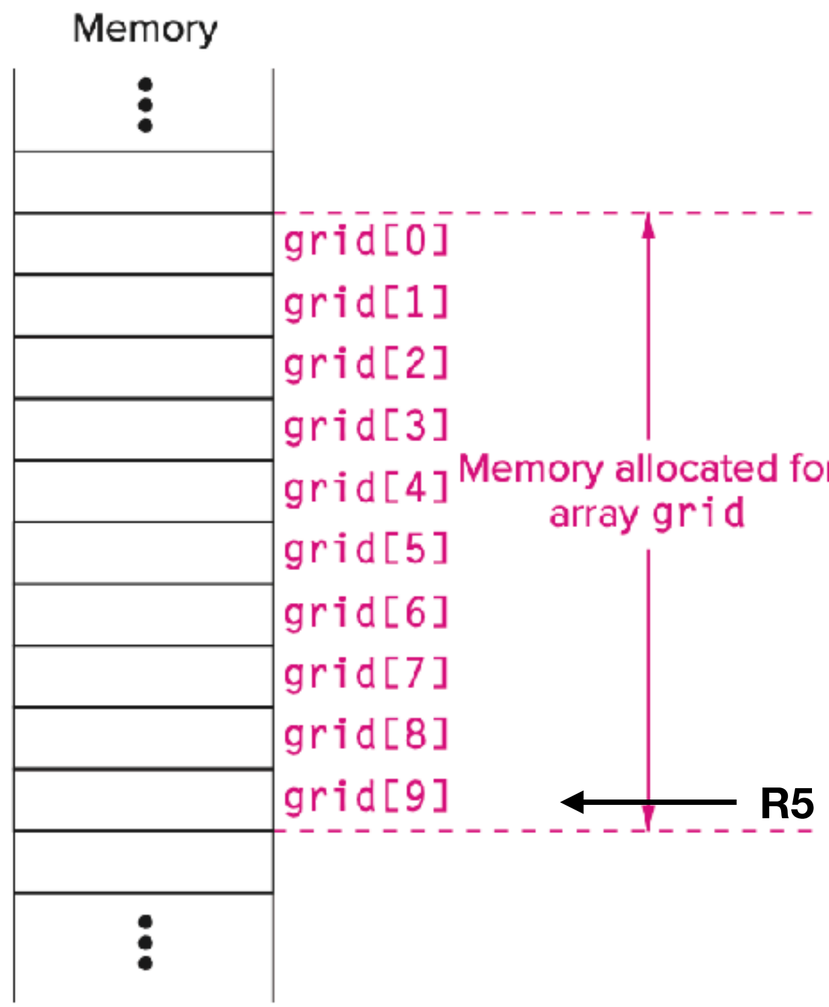


Arrays in LC-3

- The declaration `int grid[10];` allocates 10 integer sized consecutive memory locations on the *stack*.

```
grid[6] = grid[3] + 1;
```

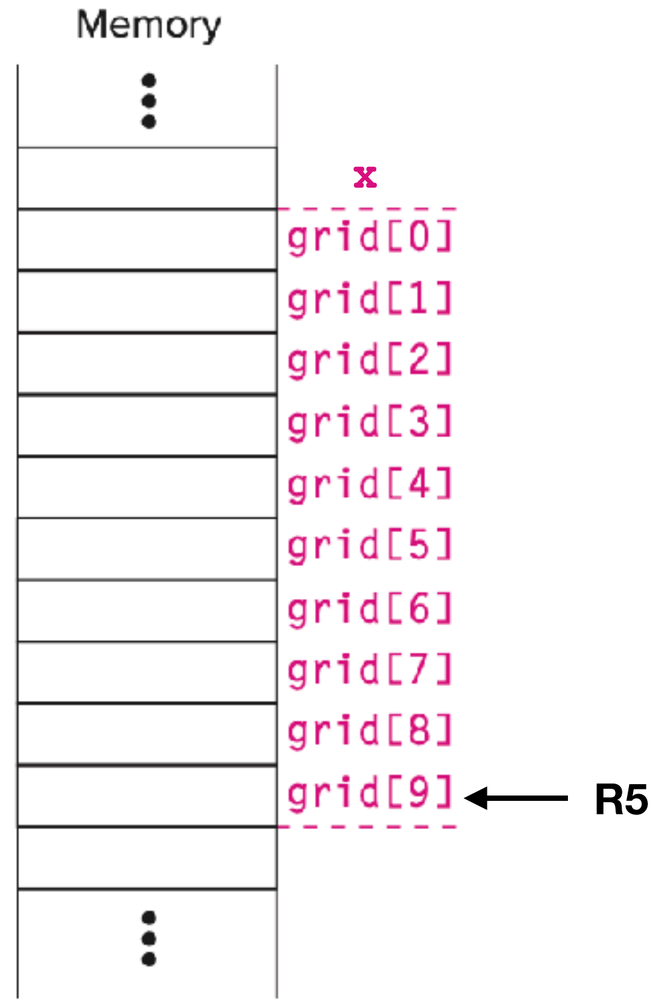
```
ADD R0, R5, #-9 ; Base address of grid
LDR R1, R0, #3  ; R1 <-- grid[3]
ADD R1, R1, #1  ; R1 <-- grid[3] + 1
STR R1, R0, #6  ; grid[6] = grid[3] + 1;
```



Arrays in LC-3

```
grid[x+1] = grid[x] + 2;
```

```
LDR R0, R5, #-10 ; Load the value of x
ADD R1, R5, #-9  ; Base address of grid
ADD R1, R0, R1   ; Calculate address of grid[x]

LDR R2, R1, #0   ; R2 <-- grid[x]
ADD R2, R2, #2   ; R2 <-- grid[x] + 2

LDR R0, R5, #-10 ; Load the value of x
ADD R0, R0, #1   ; R0 <-- x + 1

ADD R1, R5, #-9  ; Base address of grid
ADD R1, R0, R1   ; Calculate address of grid[x+1]
STR R2, R1, #0   ; grid[x+1] = grid[x] + 2;
```



Strings in C

- Strings in C are simply arrays of chars and declared in the same format:

```
char my_name[10];
```

- And can also be initialized like other arrays:

```
char my_name[10] = “is Ivan”
```

Note “ vs. ‘

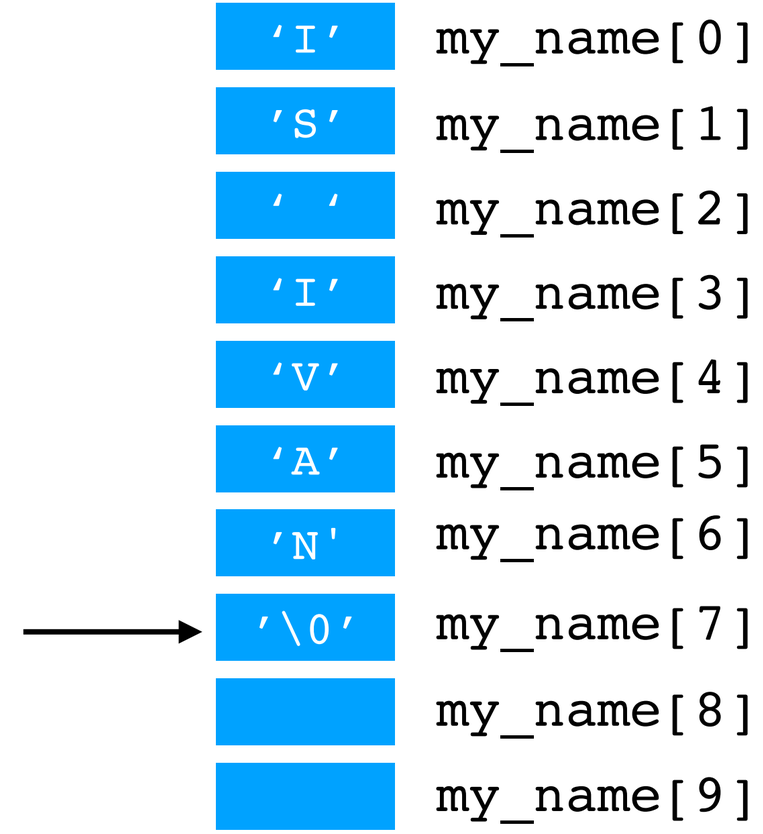
Did not use all 10 characters - some are unused

Strings in C

- To use strings with `printf` use the format specifier `%s`:

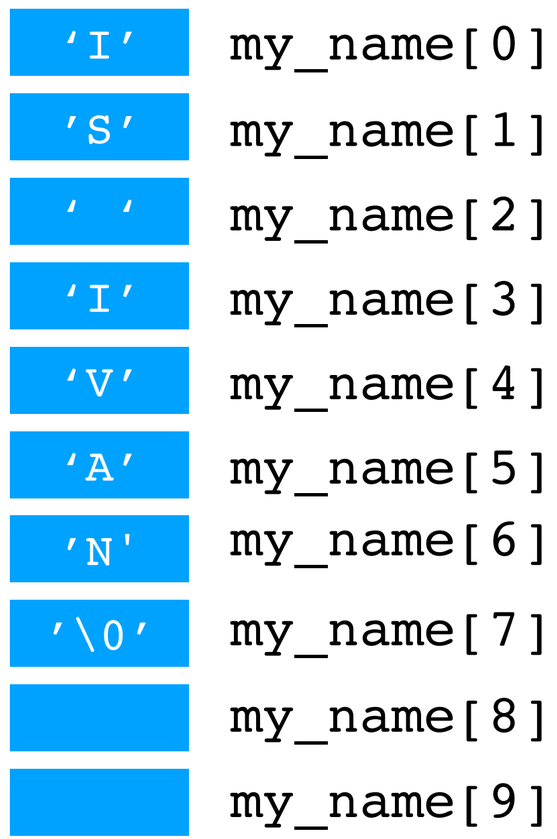
```
printf("My name %s", my_name);
```

- How does C know not to print garbage from the unused memory locations?
  - *Null-termination* for strings.



Strings in C

- Thus, the *length* of a string need not be the same as the size of the memory allocated to its identifier.
  - Food for thought: Write a function to determine the *length* of a string.



- **Note**: To replace the space in `my_name[2]` with an underscore do:

```
my_name[2] = '_';
```

Single quote

Accepting keyboard input

- So far we used `scanf` to accept keyboard input.

- Run code on right with input “ECE 220” typed in from the console.

- What happened?

```c
#include <stdio.h>

int main(void){
   char mystr[10];
   char mychar;
   printf("Enter a string:\t");
   scanf("%s", mystr);
   printf("\nYou entered: %s", mystr);
   printf("\nEnter a character:\t");
   scanf("%c", &mychar);
   printf("\nYou entered: %c\n", mychar);
   return 0;
}
```

Accepting keyboard input

- We can avoid that using the `fgets` function.

- Is that the only way to fix the issue?

  - **Answer**: No. Could use regexes:

```
scanf(“%[^\n]”, mystr);
```

```c
#include <stdio.h>

int main(void){
  char mystr[10];
  char mychar;
  printf("Enter a string:\t");
  fgets(mystr, 10, stdin);
  printf("\nYou entered: %s", mystr);
  printf("\nEnter a character:\t");
  scanf("%c", &mychar);
  printf("\nYou entered: %c\n", mychar);
  return 0;
}
```

Syntax: `fgets(charbuf, buf_size, source)`

Parsing string inputs

- Often we want to parse user input in a certain way.
- For example if the user enters: `217-333-2300` we may want to store it as three integer variables: `area_code, prefix, pnum`.
- We use the `sscanf` function.

```
sscanf(char_buffer, format_string, variables…)
```

Example

- Write a C program that will parse user input of a sequence of digits in the format `xxx-xxx-xxxx` as 10 digit phone number. In other words into an area code, prefix and a local identifying number. Print each out to the console separately.

Example

Why 13?

What if input did not fit given format?

Need to check return or exit codes.

```c
#include <stdio.h>

int main(void){
  int area_code, prefix, pnum;
  char mystr[13];

  printf("Enter a 10-digit phone number.\n");
  printf("Format: xxx-xxx-xxxx\n");

  fgets(mystr, 13, stdin);
  sscanf(mystr, "%d-%d-%d", &area_code, &prefix, &pnum);

  printf("\nArea code: %d", area_code);
  printf("\nPrefix: %d", prefix);
  printf("\nLocal: %d", pnum);

  return 0;
}
```

`sscanf` will return number of values correctly parsed

Entering multiple strings?

```c
#include <stdio.h>

int main(void){
char arr[][6] = {"cat",
                 "horse",
                 "golf"};

int i;
printf("Elements are:\n");
for (i = 0; i < 3; i++)
   printf("%s\n", arr[i]);
}

arr[1] = "cat";
}
```

Memory allocation

arr[0]	c	a	t	\0		
arr[1]	h	o	r	s	e	\0
arr[2]	g	o	l	f	\0	

→ Compiler error! Cannot assign to array.

To modify character arrays after declaration use `strcpy` from `<string.h>` (which also houses a `strlen` function just FYI).

Strings - subtle points

- Common point of confusion responsible for much frustration is conflating *character arrays* with *string literals*.

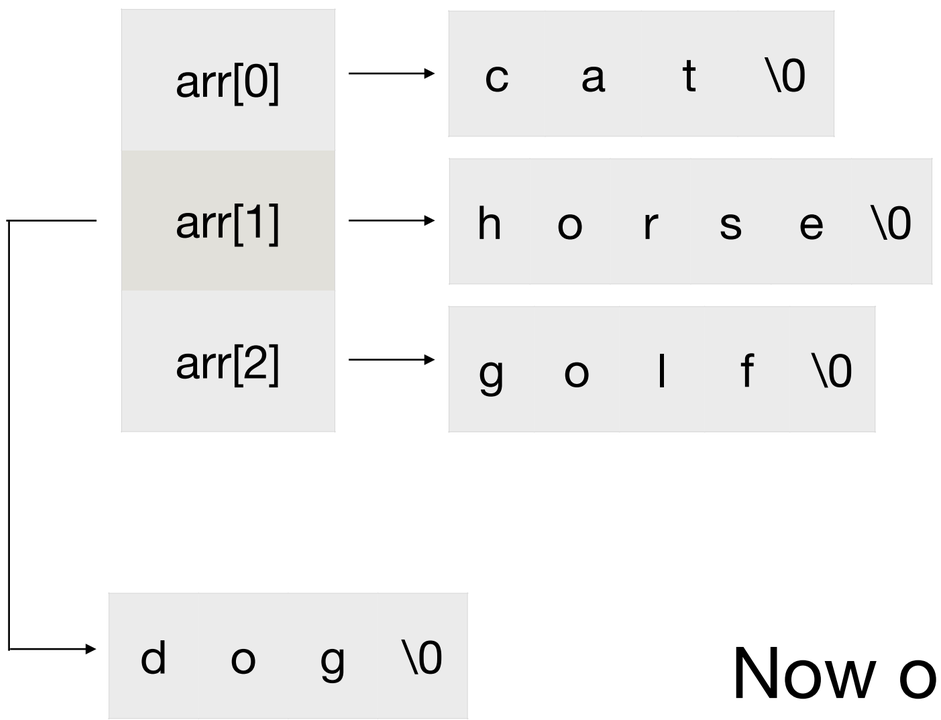
- You will often see the code from the previous slide written this way.

- But they are **NOT** equivalent.

```c
#include <stdio.h>

int main(void){
char *arr[3] = {"cat",
                "horse",
                "golf"};
int i;

printf("Elements are:\n");
for (i = 0; i < 3; i++)
   printf("%s\n", arr[i]);

arr[1] = "dog";
}
```

Strings - subtle points

Memory allocation




```c
#include <stdio.h>

int main(void){
char *arr[3] = {"cat",
               "horse",
               "golf"};

printf("Elements are:\n");
for (int i = 0; i < 3; i++)
   printf("%s\n", arr[i]);

arr[1] = "dog";
}
```

Now okay!

Strings - subtle points

These are allocated on the stack and so `arr` remains modifiable.

```c
#include <stdio.h>

int main(void){
char arr[3][6] = {"cat",
                  "horse",
                  "golf"};

printf("Elements are:\n");
for (int i = 0; i < 3; i++)
   printf("%s\n", arr[i]);
}

arr[0][1] = 'o';
}
```

Okay.

These are stored as *string literals*, often in read-only memory. `arr` just points to them.

```c
#include <stdio.h>

int main(void){
char *arr[3] = {"cat",
                "horse",
                "golf"};

printf("Elements are:\n");
for (int i = 0; i < 3; i++)
   printf("%s\n", arr[i]);

arr[0][1] = 'o';
}
```

Undefined behavior!

Multi-dimensional arrays

- C allows for defining *multi-dimensional* arrays (we already saw them with string arrays).

One dimensional array

0	1	2	3

- The *dimension* of an array is determined by the minimum number of indices required to access its individual elements.

Two dimensional array

0,0	0,1	0,2	0,3
1,0	1,1	1,2	1,3
2,0	2,1	2,2	2,3

Multi-dimensional arrays

- The syntax for two dimensional arrays is:

```
type varname[nr][nc];
```

where `nr` and `nc` are the number of rows & columns.

- Example: `int a[3][4];`

One dimensional array

a[0]	a[1]	a[2]	a[3]

Two dimensional array

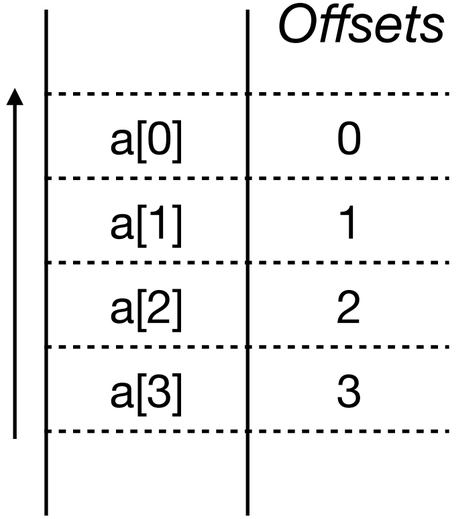
a[0][0]	a[0][1]	a[0][2]	a[0][3]
a[1][0]	a[1][1]	a[1][2]	a[1][3]
a[2][0]	a[2][1]	a[2][2]	a[2][3]

Initializing 2D arrays

- There are multiple ways to initialize a 2D array.
- Here are *four* equivalent ways to initialize a 2×3 array:
  - `int a[2][3] = {{1,2,3},{4,5,6}};`
  - `int a[2][3] = {1,2,3,4,5,6};`
  - `int a[][3] = {{1,2,3},{4,5,6}};`
  - `int a[][3] = {1,2,3,4,5,6};`
- Why not: `int a[2][] = {{1,2,3},{4,5,6}};` ?

Allocating memory

One dimensional array



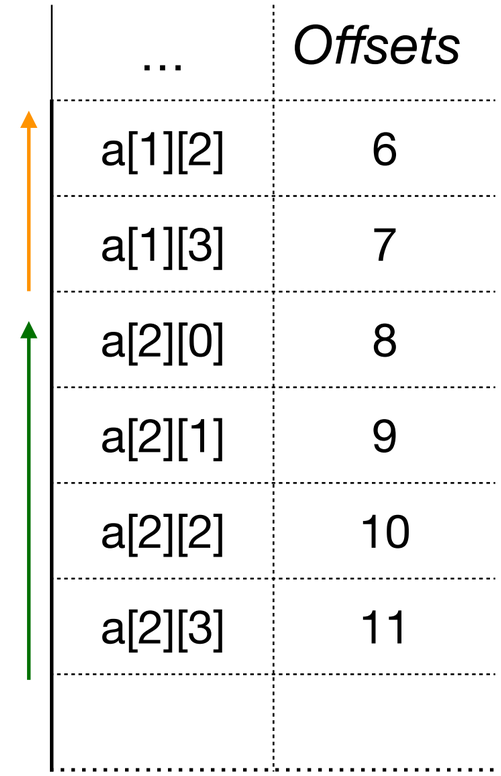
	Offsets
a[0]	0
a[1]	1
a[2]	2
a[3]	3

How to calculate offset?

```
offset = ri * nc + ci
```

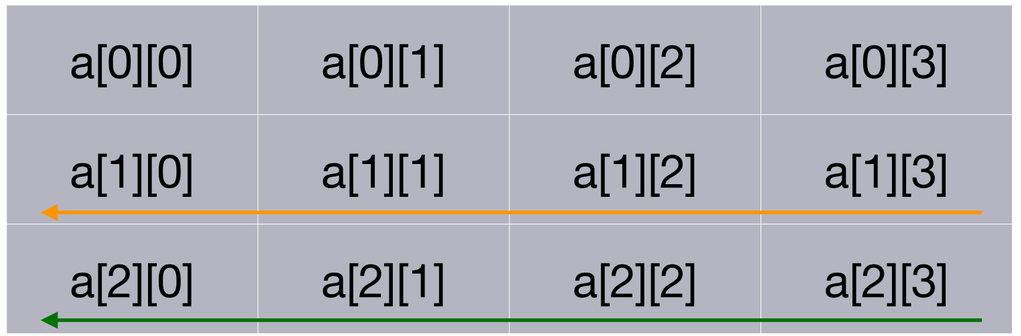
Row index

Column index



…	*Offsets*
a[1][2]	6
a[1][3]	7
a[2][0]	8
a[2][1]	9
a[2][2]	10
a[2][3]	11

Two dimensional array



a[0][0]	a[0][1]	a[0][2]	a[0][3]
a[1][0]	a[1][1]	a[1][2]	a[1][3]
a[2][0]	a[2][1]	a[2][2]	a[2][3]

C follows what is called *row-major order*, i.e rows first.

More than 2D?

- C allows creating arrays with multiple dimensions.
- Example: Here is a three dimensional array where the first dimension has size `x`, the second dimension has size `y` and last dimension has size `z`.

```
int arr3d[x][y][z];
```

- **Question**: How will `arr3d[4][3][2]` be stored in memory?
  - Hint 1: *Last index varies fastest.*
  - Hint 2: Element `arr3d[x-1][y-1][z-1]` will be bottom most.