CS103 Unit 5 - Arrays

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ARRAY BASICS

Need for Arrays

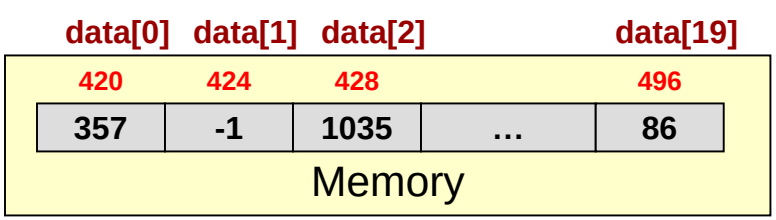
- If I want to keep the score of 100 players in a game I could declare a separate variable to track each one's score:
  - `int player1 = N; int player2 = N; int player3 = N; …`
  - PAINFUL!!
- Enter **arrays**
  - Ordered collection of variables of the same type
  - Collection is referred to with one name
  - Individual elements referred to by an offset/index from the start of the array [in C, first element is at index 0]
- Example:
  - int player[100];

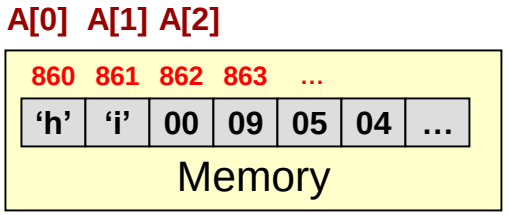
Arrays: Informal Overview

- Informal Definition:
  - Ordered collection of variables of the same type
- Collection is referred to with one name
- Individual elements referred to by an offset/index from the start of the array [in C, first element is at index 0]

```
int data[20];
data[0] = 357;
data[1] = -1;
data[2] = 1035;
int x = data[0];
```

```
char  A[3] = "hi";
```

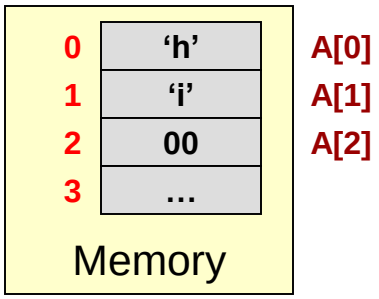




Arrays

- Informal Def: Collection of variables of the same type accessed by index/position
- Formal Def: A statically-sized, contiguously allocated collection of homogenous data elements
- Collection of homogenous data elements
  - Multiple variables of the same data type
- Contiguously allocated in memory
  - One right after the next
- Statically-sized
  - Size of the collection must be a constant and can't be changed after initial declaration/allocation
- Collection is referred to with one name
- Individual elements referred to by an offset/index from the start of the array [in C, first element is at index 0]

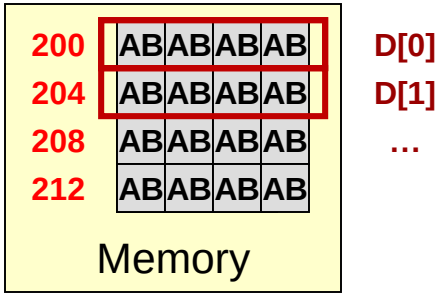
char A[3] = "hi";



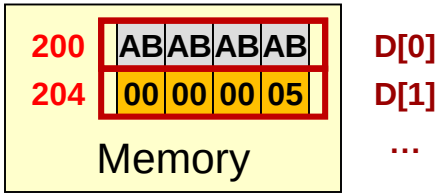
char c = A[0]; // 'h'

---

int D[20];

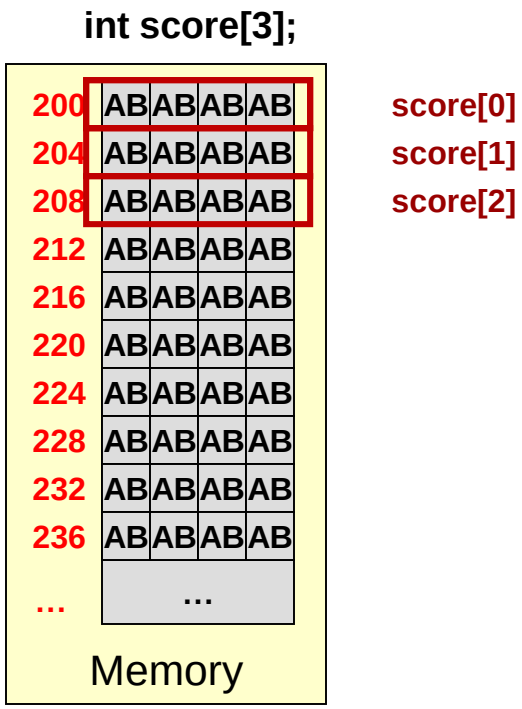


D[1] = 5;



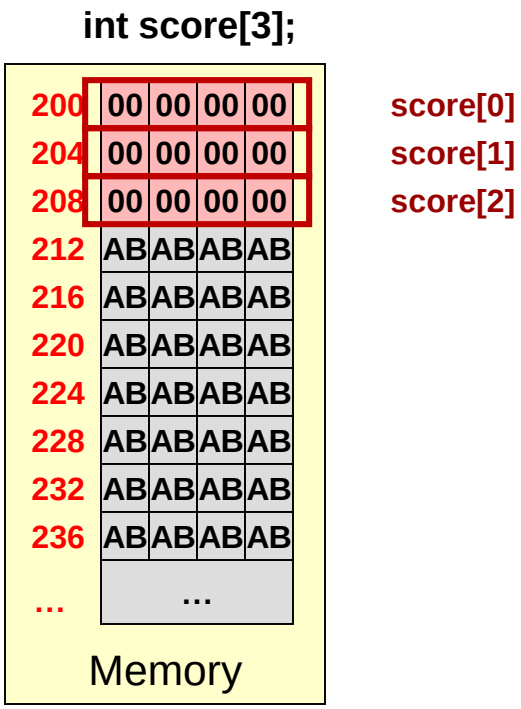
Example: Arrays

- Track the score of 3 players
- Homogenous data set (amount) for multiple people…perfect for an array
  - `int score[3];`
- Recall, memory has garbage values by default. You will need to initialized each element in the array



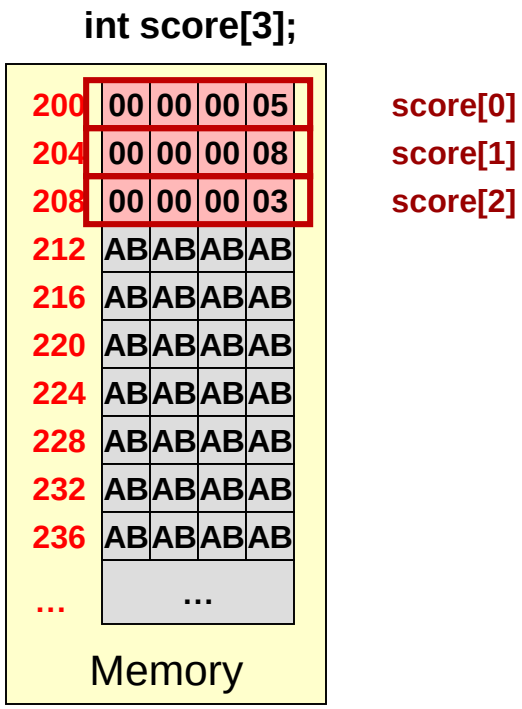
Example: Arrays

- Track the score of 3 players
- Homogenous data set (amount) for multiple people…perfect for an array
  - `int score[3];`
- Must initialize elements of an array
  - `for(int i=0; i < 3; i++)`
    `score[i] = 0;`



Arrays

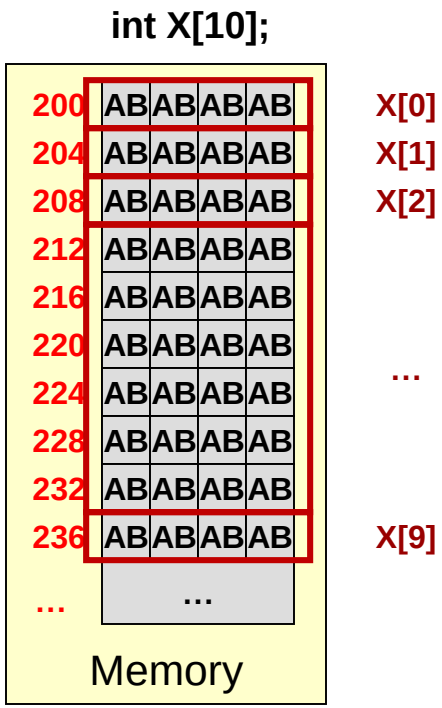
- Track the score of 3 players
- Homogenous data set (amount) for multiple people…perfect for an array
  - `int score[3];`
- Must initialize elements of an array
  - ```
    for(int i=0; i < 3; i++)
        score[i] = 0;
    ```
- Can access each persons amount and perform ops on that value
  - ```
    score[0] = 5;
    score[1] = 8;
    score[2] = score[1] - score[0]
    ```



ARRAY ODDS AND ENDS

Static Size/Allocation

- For now, arrays must be declared as fixed size (i.e. a constant known at compile time)
  - Good:
    - `int x[10];`
    - `#define MAX_ELEMENTS  100`
      `int x[MAX_ELEMENTS];`
    - `const int MAX_ELEMENTS = 100;`
      `int x[MAX_ELEMENTS];`
  - Bad:
    - `int mysize;`
      `cin >> mysize;`
      `int x[mysize];`
    - `int mysize = 10;`
      `int x[mysize];`



Compiler must be able to figure out how much memory to allocate at compile-time

Initializing Arrays

- Integers or floating point types can be initialized by placing a comma separated list of values in curly braces {…}
  - int data[5] = {4,3,9,6,14};
  - char vals[8] = {64,33,18,4,91,76,55,21};
- If accompanied w/ initialization list, size doesn't have to be indicated (empty [ ])
  - double stuff[] = {3.5, 14.22, 9.57}; // = stuff[3]
- However the list must be of constants, not variables:
  - BAD: double z = 3.5; double stuff[] = {z, z, z};

Understanding array addressing and indexing

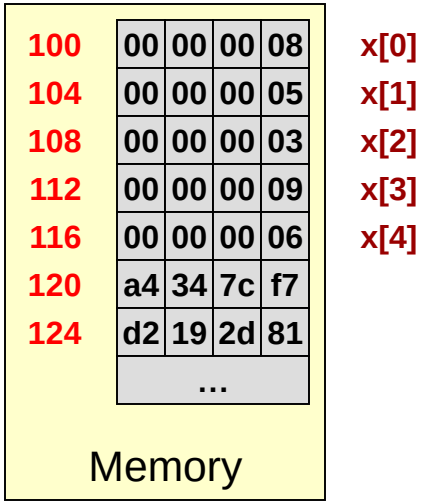
ACCESSING DATA IN AN ARRAY

Exercise

- Consider a train of box cars
  - The initial car starts at point A on the number line
  - Each car is 5 meters long
- Write an expression of where the i-th car is located (at what meter does it start?)
- Suppose a set of integers start at memory address A, write an expression for where the i-th integer starts?
- Suppose a set of doubles start at memory address A, write an expression for where the i-th double starts?

More on Accessing Elements

- Assume a 5-element int array
  - int x[5] = {8,5,3,9,6};
- When you access x[2], the CPU calculates where that item is in memory by taking the start address of x (i.e. 100) and adding the product of the index, 2, times the size of the data type (i.e. int = 4 bytes)
  - x[2] => int. @ address 100 + 2*4 = 108
  - x[3] => int. @ address 100 + 3*4 = 112
  - x[i] @ start address of array + i * (size of array type)
- C does not stop you from attempting to access an element beyond the end of the array
  - x[6] => int. @ address 100 + 6*4 = 124 (Garbage!!)



Compiler must be able to figure out how much memory to allocate at compile-time

Fun Fact 1: If you use the **name of an array** w/o square brackets it will evaluate to the **starting address** in memory of the array (i.e. address of 0th entry)
Fun Fact 2: Fun Fact 1 usually appears as one of the first few questions on the midterm.

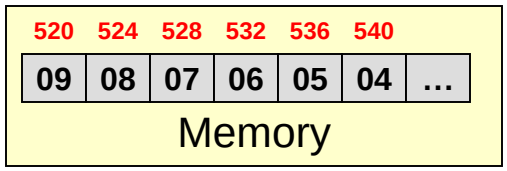
Intermediate-Level Array Topics

Passing arrays to other functions

ARRAYS AS ARGUMENTS

Passing Arrays as Arguments

- In function declaration / prototype for the ***formal*** parameter use
  - "type []" or "type *" to indicate an array is being passed
- When calling the function, simply provide the name of the array as the ***actual*** argument
  - **In C/C++ using an array name without any index evaluates to the starting address of the array**
- C does NOT implicitly keep track of the size of the array
  - Thus either need to have the function only accept arrays of a certain size
  - Or need to pass the size (length) of the array as another argument




```
void add_1_to_array_of_10(int []);
void add_1_to_array(int *, int);
int main(int argc, char *argv[])
{
  int data[10] = {9,8,7,6,5,4,3,2,1,0};
  add_1_to_array_of_10(data);
  cout << "data[0]" << data[0] << endl;
  add_1_to_array(data,10);
  cout << "data[9]" << data[9] << endl;
  return 0;
}
// Example syntax 1
void add_1_to_array_of_10(int my_array[])
{
  int i=0;
  for(i=0; i < 10; i++){
    my_array[i]++;
  }
}
// Example syntax 2
void add_1_to_array(int *my_array, int size)
{
  int i=0;
  for(i=0; i < size; i++){
    my_array[i]++;
  }
}
```

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Passing Arrays as Arguments

- In function declaration / prototype for the ***formal*** parameter use ***type [ ]***
- When calling the function, simply provide the name of the array as the ***actual*** argument
- Scalar values (int, double, char, etc.) are "**passed-by-value**"
  - Copy is made and passed
- Arrays are "**passed-by-reference**"
  - We are NOT making a copy of the entire array (that would require too much memory and work) but passing a reference to the actual array (i.e. an address of the array)
  - Thus any changes made to the array data in the called function will be seen when control is returned to the calling function.

```
void f1(int []);

int main(int argc, char *argv[])
{
  int data[10] = {10,11,12,13,14,
                  15,16,17,18,19};
  cout << "Loc. 0=" << data[0] << endl;
  cout << "Loc. 9=" << data[9] << endl;

  f1(data);   520

  cout << "Loc. 0=" << data[0] << endl;
  cout << "Loc. 9=" << data[9] << endl;
  return 0;
}

                    520
void f1(int my_array[])
{
  int i=0;
  for(i=0; i < 10; i++){
    my_array[i]++;
  }
}
```

Output:

```
Loc. 0=10
Loc. 9=19
Loc. 0=11
Loc. 9=20
```

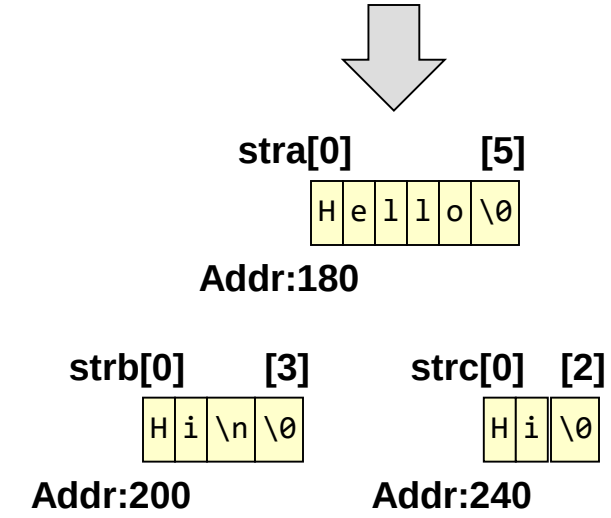
Null terminated character arrays

C-STRINGS

C Strings

- Character arrays (i.e. C strings)
  - Enclosed in double quotes " "
  - Strings of text are simply arrays of chars
  - Can be initialized with a normal C string (in double quotes)
  - C strings have one-byte (char) per character
  - End with a "null" character = 00 dec. = '\0' ASCII
  - cout "knows" that if a char array is provided as an argument it will print the 0th character and keep printing characters until a '\0' (null) character [really just a value of 0] is encountered
  - cin "knows" how to take in a string and fill in a char array (stops at whitepace)
    - Careful it will write beyond the end of an array if the user enters a string that is too long

```
#include<iostream>
using namespace std;
int main()
{
  char stra[6] = "Hello";
  char strb[] = "Hi\n";
  char strc[] = {'H','i','\0'};
  cout << stra << strb;
  cout << strc << endl;
  cout << "Now enter a string: ";
  cin >> stra;
  cout << "You typed: " << stra;
  cout << endl;
}
```



Example: C String Functions

- Write a function to determine the length (number of characters) in a C string
- Write a function to copy the characters in a source string/character array to a destination character array
- Copy the template to your account
  - wget http://ee.usc.edu/~redekopp/cs103/string_funcs.cpp
- Edit and test your program and complete the functions:
  - int strlen(char str[])
  - strcpy(char dst[], char src[])
- Compile and test your functions
  - main() is complete and will call your functions to test them

Using arrays as a lookup table

LOOKUP TABLES

Arrays as Look-Up Tables

- Use the value of one array as the index of another
- Suppose you are given some integers as data [in the range of 0 to 5]
- Suppose computing squares of integers was difficult (no built-in function for it)
- Could compute them yourself, record answer in another array and use data to "look-up" the square

```
// the data
int data[8] = {3, 2, 0, 5, 1, 4, 5, 3};

// The LUT
int squares[6] = {0,1,4,9,16,25};
```

```
// the data
int data[8] = {3, 2, 0, 5, 1, 4, 5, 3};

// The LUT
int squares[6] = {0,1,4,9,16,25};

for(int i=0; i < 8; i++){
  int x = data[i]
  int x_sq = squares[x];
  cout << i << "," << sq[i] << endl;
}
```

```
// the data
int data[8] = {3, 2, 0, 5, 1, 4, 5, 3};

// The LUT
int squares[6] = {0,1,4,9,16,25};

for(int i=0; i < 8; i++){
  int x_sq = squares[data[i]];
  cout << i << "," << sq[i] << endl;
}
```

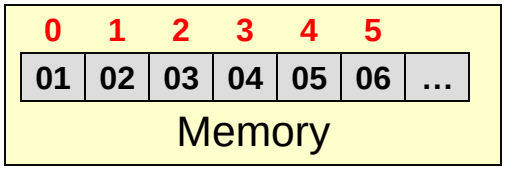
Example

- Using an array as a Look-Up Table
  - wget http://ee.usc.edu/~redekopp/cs103/cipher.cpp
  - Let's create a cipher code to encrypt text
  - `abcdefghijklmnopqrstuvwxyz => ghijklmaefnzyqbcdrstuopvwx`
  - char orig_string[] = "helloworld";
  - char new_string[11];
  - After encryption:
    - new_string = "akzzbpbrzj"
  - Define another array
    - char cipher[27] = "ghijklmaefnzyqbcdrstuopvwx";
    - How could we use the original character to index ("look-up" a value in) the cipher array

MULTIDIMENSIONAL ARRAYS

Multidimensional Arrays

- Thus far arrays can be thought of 1-dimensional (linear) sets
  - only indexed with 1 value (coordinate)
  - char x[6] = {1,2,3,4,5,6};
- We often want to view our data as 2-D, 3-D or higher dimensional data
  - Matrix data
  - Images (2-D)
  - Index w/ 2 coordinates (row,col)



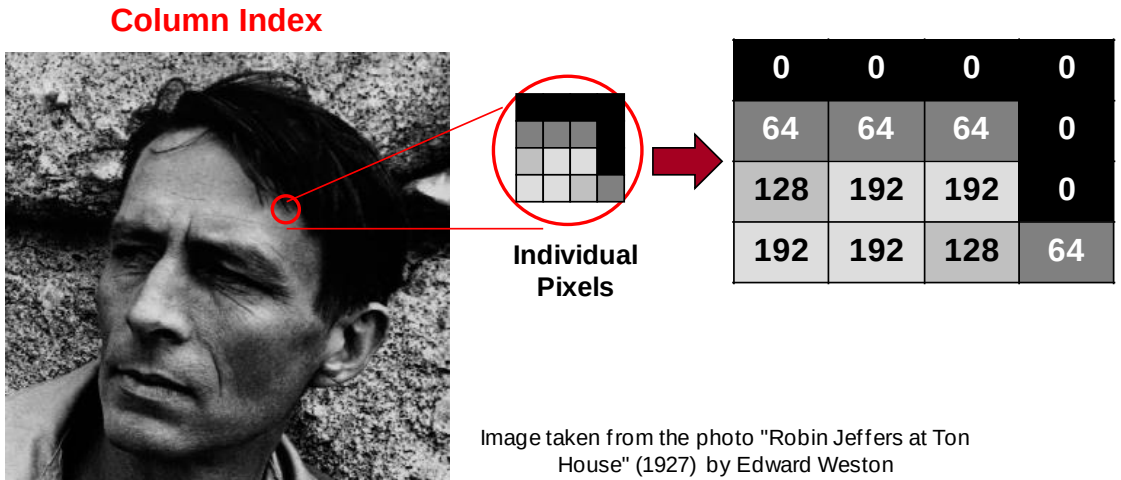


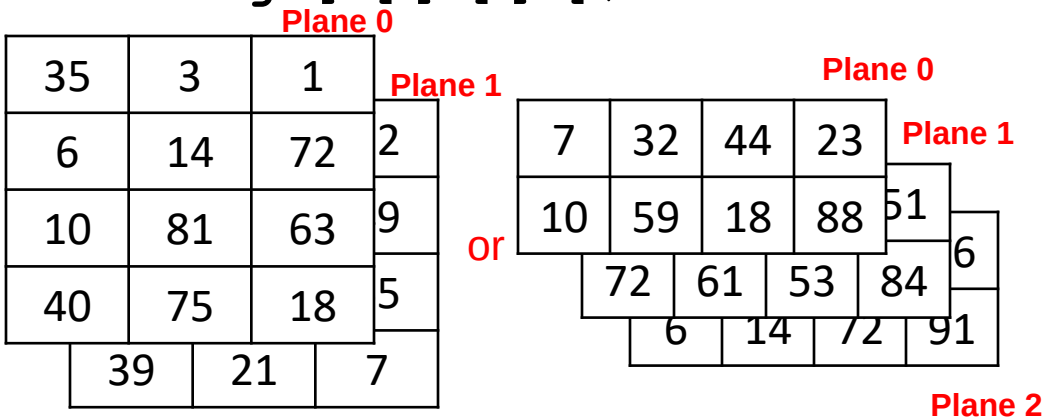
Image taken from the photo "Robin Jeffers at Ton House" (1927) by Edward Weston

Multidimension Array Declaration

- 2D: Provide size along both dimensions (normally rows first then columns)
  - Access w/ 2 indices
  - Declaration: **`int my_matrix[2][3];`**
  - Access elements with appropriate indices
    - my_matrix[0][1] evals to 3, my_matrix [1][2] evals to 2

	Col. 0	Col. 1	Col. 2
Row 0	5	3	1
Row 1	6	4	2

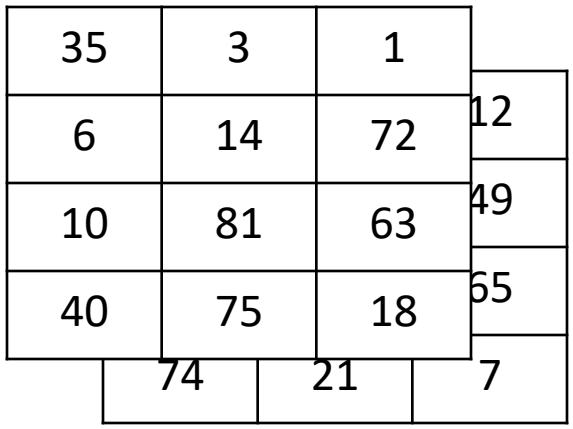
- 3D: Access data w/ 3 indices
  - Declaration: **`unsigned char image[2][4][3];`**
  - Up to human to interpret meaning of dimensions
    - Planes x Rows x Cols
    - Rows x Cols x Planes

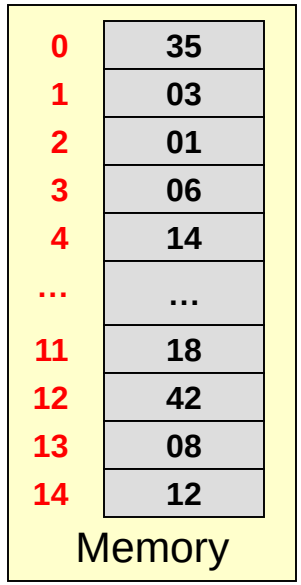


Passing Multi-Dimensional Arrays

- Formal Parameter: Must give dimensions of all but first dimension
- Actual Parameter: Still just the array name (i.e. starting address)
- Why do we have to provide all but the first dimension?
- So that the computer can determine where element: data[i][j][k] is actually located in memory

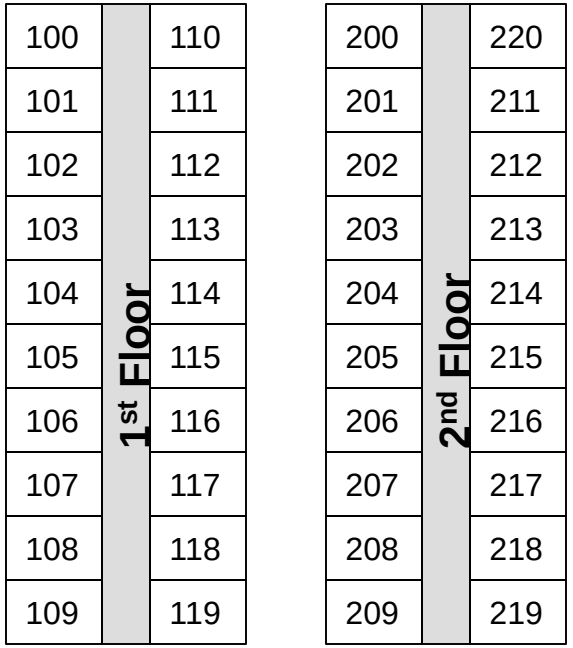
```
void doit(int my_array[][4][3])
{
  my_array[1][3][2] = 5;
}

int main(int argc, char *argv[])
{
  int data[2][4][3];

  doit(data);
  ...
  return 0;
}
```





Linearization of Multidimensional Arrays

- Analogy: Hotel room layout => 3D
  - Access location w/ 3 indices:
    - Floors, Aisles, Rooms
    - But they don't give you 3 indices, they give you one room number
  - Room #'s are a linearization of the 3 dimensions
    - Room 218 => Floor=2, Aisle 1, Room 8
- When "linear"-izing we keep proximity for one dimension
  - Room 218 is next to 217 and 219
- But we lose some proximity info for higher dimensions
  - Presumably room 218 is right below room 318
  - But in the linearization 218 seems **very** far from 318



Analogy: Hotel Rooms

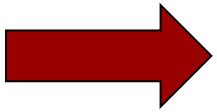
1st Digit = Floor
2nd Digit = Aisle
3rd Digit = Room

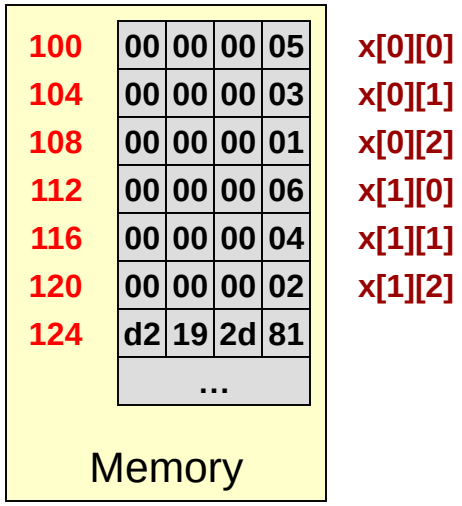
Linearization of Multidimensional Arrays

- In a computer, multidimensional arrays must still be stored in memory which is addressed linearly
  (1-Dimensional)
- C/C++ use a policy that lower dimensions are placed next to each other followed by each higher level dimension

int x[2][3];

	Col. 0	Col. 1	Col. 2
Row 0	5	3	1
Row 1	6	4	2





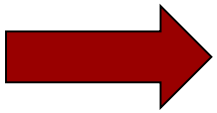
Linearization of Multidimensional Arrays

- In a computer, multidimensional arrays must still be stored in memory which is addressed linearly (1-Dimensional)
- C/C++ use a policy that lower dimensions are placed next to each other followed by each higher level dimension

char y[2][4][3];

35	3	1
6	14	72
10	81	63
40	75	18

42	8	12
67	25	49
14	48	65
74	21	7



0	35
1	03
2	01
3	06
4	14
…	…
11	18
12	42
13	08
14	12

Memory

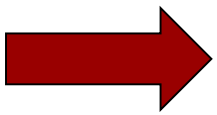
Linearization of Multidimensional Arrays

- We could re-organize the memory layout (i.e. linearization) while still keeping the same view of the data by changing the order of the dimensions

char y[4][3][2];

35	3	1
6	14	72
10	81	63
40	75	18

42	8	12
67	25	49
14	48	65
74	21	7



0	35
1	42
2	03
3	08
4	01
5	12
6	06
7	67
8	14
…	…

Memory

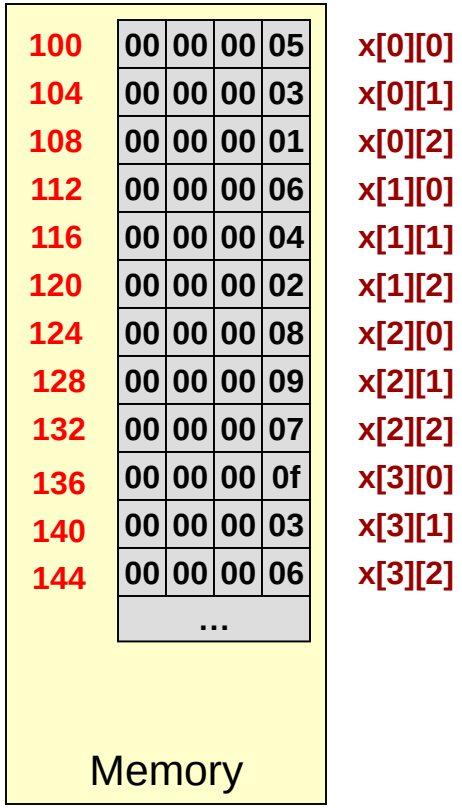
Linearization of Multidimensional Arrays

- Formula for location of item at row i, column j in an array with NUMR rows and NUMC columns:

Declaration: `int x[2][3]; // NUMR=2, NUMC = 3;`

	Col. 0	Col. 1	Col. 2
Row 0	5	3	1
Row 1	6	4	2
Row 2	8	9	7
Row 3	15	3	6

Access: `x[i][j]:`



Linearization of Multidimensional Arrays

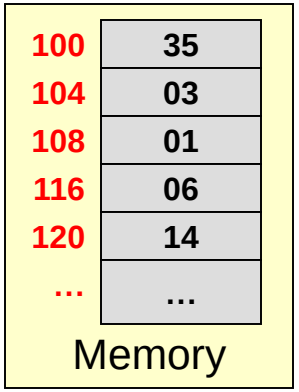
- Formula for location of item at plane p, row i, column j in array with NUMP planes, NUMR rows, and NUMC columns

Declaration: `int x[2][4][3]; // NUMP=2, NUMR=4, NUMC=3`

Access: `x[p][i][j]:`

35	3	1
6	14	72
10	81	63
40	75	18

42	8	12
67	25	49
14	48	65
74	21	7



Revisited: Passing Multi-Dimensional Arrays

- Must give dimensions of all but first dimension
- This is so that when you use 'myarray[p][i][j]' the computer and determine where in the linear addresses that individual index is located in the array
  - `[p][i][j] = startAddr + (p*NUMR*NUMC + i*NUMC + j)*sizeof(int)`
  - [1][3][2] in an array of nx4x3 becomes: 1*(4*3) + 3(3) + 2 = 23 ints = 23*4 = 92 bytes into the array

```
void doit(int my_array[][4][3])
{
  my_array[1][3][2] = 5;
}

int main(int argc, char *argv[])
{
  int data[2][4][3];

  doit(data);
  ...
  return 0;
}
```

35	3	1
6	14	72
10	81	63
40	75	18
74	21	7

12
49
65

100	35
104	03
108	01
112	06
116	14
...	...
144	18
148	42
152	08
156	12

Memory

Using 2- and 3-D arrays to create and process images

IMAGE PROCESSING

Practice: Drawing

- Download the BMP library code:
  - In your examples directory on your VM
    - $ wget http://bits.usc.edu/files/cs103/demo-bmplib.tar
    - $ tar -xvf demo-bmplib.tar
    - $ cd demo-bmplib
    - $ make
    - $ ./demo
    - $ eog cross.bmp &
  - Code to read (open) and write (save) .BMP files is provided in bmplib.h and bmplib.cpp
  - Look at bmplib.h for the prototype of the functions you can use in your main() program in gradient.cpp

Multi-File Programs

- We need a way to split our code into many separate files so that we can partition our code
  - We often are given code libraries from other developers or companies
  - It can also help to put groups of related functions into a file
- bmplib.h has prototypes for functions to read, write, and show .BMP files as well as constant declarations
- bmplib.cpp has the implementation of each function
- cross.cpp has the main application code
  - It #include's the .h file so as to have prototypes and constants available

Key Idea: The ***.h*** file tells you ***what*** library functions are available; The ***.cpp*** file tells you ***how*** it does it

Multi-file Compilation

- Three techniques to compile multiple files into a single application
  - Use 'make' with a 'Makefile' script
    - We will provide you a 'Makefile' whenever possible and it contains directions for how to compile all the files into a single program
    - To use it just type 'make' at the command prompt
  - Compile all the .cpp files together like:

    $ **compile gradient.cpp bmplib.cpp -o gradient**
    - Note: NEVER compile .h files

Multi-file Compilation

- Three techniques to compile multiple files into a single application
  - Compile each .cpp files separately into an "object file" (w/ the –c option) and then link them altogether into one program:

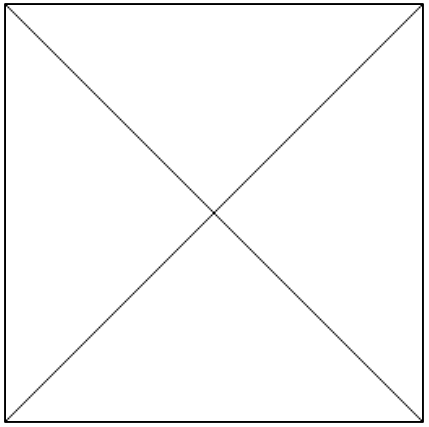
    $ compile **-c** bmplib.cpp -o bmplib.o

    $ compile **-c** gradient.cpp -o gradient.o

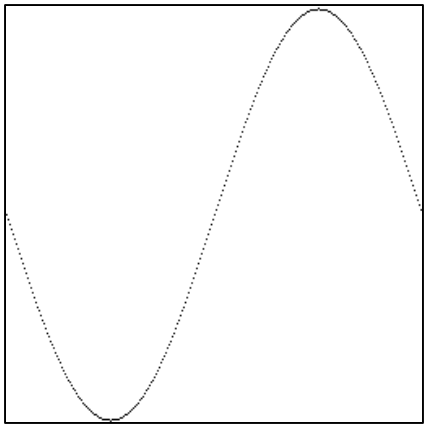
    $ compile gradient.o bmplib.o -o gradient
  - The first two command produce .o (object) files which are non-executable files of 1's and 0's representing the code
  - The last command produces an executable program by putting all the .o files together
  - Don't do this approach in 103, but it is approach 'Makefiles' use and the way most real programs are compiled

Practice: Drawing

- Draw an X on the image
  - Try to do it with only a single loop, not two in sequence

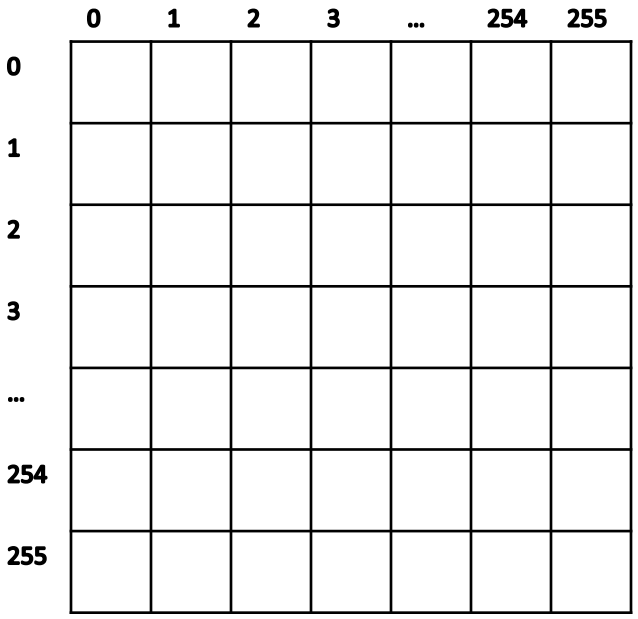


- Draw a single period of a sine wave
  - Hint: enumerate each column, x, with a loop and figure out the appropriate row (y-coordinate)



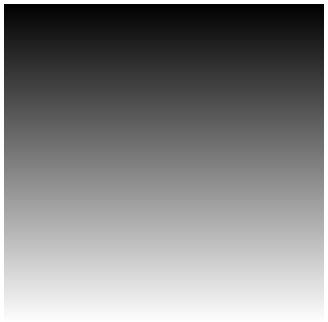
Scratch Workspace

- Identify patterns in indices of what you want to draw



Practice: Drawing

- Modify gradient.cpp to draw a black cross on a white background and save it as 'output1.bmp'
- Modify gradient.cpp to draw a black X down the diagonals on a white background and save it as 'output2.bmp'
- Modify gradient.cpp to draw a gradient down the rows (top row = black through last row = white with shades of gray in between
- Modify gradient.cpp to draw a diagonal gradient with black in the upper left through white down the diagonal and then back to black in the lower right



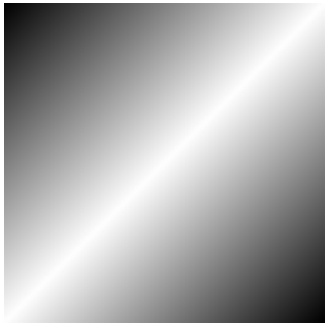
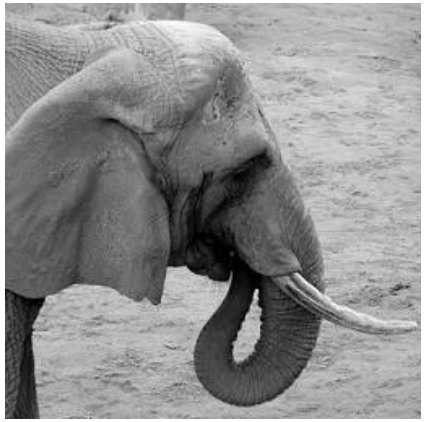


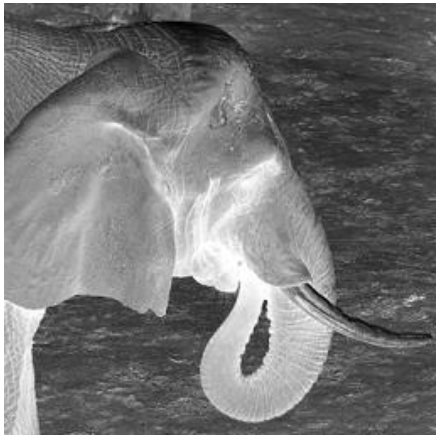
Image Processing

- Go to your gradient directory
  - $ wget http://bits.usc.edu/files/cs103/graphics/elephant.bmp
- Here is a first exercise…produce the "negative"



Original

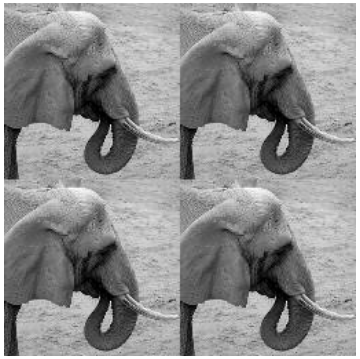
```
#include "bmplib.h"
int main() {
   unsigned char image[SIZE][SIZE];
   readGSBMP("elephant.bmp", image);
   for (int i=0; i<SIZE; i++) {
      for (int j=0; j<SIZE; j++) {
         image[i][j] = 255-image[i][j];
         // invert color
      }
   }
   showGSBMP(image);
}
```



Inverted

Practice: Image Processing

- Perform a diagonal flip
- Tile
- Zoom



Selected Grayscale Solutions

- **X**
  - http://bits.usc.edu/files/cs103/graphics/x.cpp
- **Sin**
  - http://bits.usc.edu/files/cs103/graphics/sin.cpp
- **Diagonal Gradient**
  - http://bits.usc.edu/files/cs103/graphics/gradient_diag.cpp
- **Elephant-flip**
  - http://bits.usc.edu/files/cs103/graphics/eg3-4.cpp
- **Elephant-tile**
  - http://bits.usc.edu/files/cs103/graphics/eg3-5.cpp
- **Elephant-zoom**
  - http://bits.usc.edu/files/cs103/graphics/zoom.cpp

Color Images

- Color images are represented as 3D arrays (256x256x3)
  - The lower dimension are Red, Green, Blue values
- Base Image
- Each color plane inverted
- Grayscaled
  - Using NTSC formula: .299R + .587G + .114B

Color Images

- Glass filter
  - Each destination pixel is from a random nearby source pixel
    - http://bits.usc.edu/files/cs103/graphics/glass.cpp

- Edge detection
  - Each destination pixel is the difference of a source pixel with its south-west neighbor

Color Images

- Smooth
  - Each destination pixel is average of 8 neighbors
    - http://bits.usc.edu/files/cs103/graphics/smooth.cpp

Original

Smoothed

Selected Color Solutions

- **Color fruit – Inverted**
  - http://bits.usc.edu/files/cs103/graphics/eg4-1.cpp
- **Color fruit – Grayscale**
  - http://bits.usc.edu/files/cs103/graphics/eg4-3.cpp
- **Color fruit – Glass Effect**
  - http://bits.usc.edu/files/cs103/graphics/glass.cpp
- **Color fruit – Edge Detection**
  - http://bits.usc.edu/files/cs103/graphics/eg5-4.cpp
- **Color fruit – Smooth**
  - http://bits.usc.edu/files/cs103/graphics/smooth.cpp

ENUMERATIONS

Enumerations

- Associates an integer (number) with a symbolic name
- `enum` *`[optional_collection_name]`* `{Item1, Item2, … ItemN}`
  - Item1 = 0
  - Item2 = 1
  - …
  - ItemN = N-1
- Use symbolic item names in your code and compiler will replace the symbolic names with corresponding integer values

```
const int BLACK=0;
const int BROWN=1;
const int RED=2;
const int WHITE=7;


int pixela = RED;
int pixelb = BROWN;
...
```

Hard coding symbolic names with given codes

```
// First enum item is associated with 0
enum Colors {BLACK,BROWN,RED,...,WHITE};


int pixela = RED;   // pixela = 2;
int pixelb = BROWN; // pixelb = 1;
```

Using enumeration to simplify

Review on your own…

COMMON ARRAY DESIGN PATTERNS

Design Pattern: Search

- A design pattern is a common recurrence of an approach
- Search: Find one item in an array/list/set of items
- Pattern:
  - Loop over each item likely using an incrementing index
  - For each item, use a conditional to check if it matches the search criteria
  - If it does match, take action (i.e. save index, add value to some answer, etc.) and possibly break, else, do nothing, just go on to next

```
// search 'data' array of size 'len' for 'target' value
bool search(int data[], int len, int target)
{ bool found = false;
  for(int i=0; i < len; i++){
    if(data[i] == target){
       found = true;
       break;
  }  }
  return found;
}
```

Design Pattern: Search

- What's not a search :
  - **Indicating the search failed if a single element doesn't match**
  - Consider data = {4, 7, 9} and target = 7
  - 4 won't match and set found=false and stop too soon

```
// search 'data' array of size 'len' for 'target' value
bool search(int data[], int len, int target)
{ bool found = false;
  for(int i=0; i < len; i++){
    if(data[i] == target)
       return true;
    else
       return false;
  }
}
```

Design Pattern: Search

- What's not a search :
  - **Indicating the search failed if a single element doesn't match**
  - Consider data = {4, 7, 9} and target = 7
  - 4 won't match and set found=false and stop too soon
  - 7 will match and set found = true, but only for a second…
  - 9 won't match and set found = false…forgetting that 7 was found

```
// search 'data' array of size 'len' for 'target' value
bool search(int data[], int len, int target)
{ bool found = false;
  for(int i=0; i < len; i++){
    if(data[i] == target)
       found = true;
    else
       found = false;
  }
  return found;
}
```

Design Pattern: Search

- What's not a search :
  - **Declaring your result variable inside the for loop**
  - Bool found only lives in the current scope (i.e. the 'if' statement and will not be visible afterwards when you need it

```
// search 'data' array of size 'len' for 'target' value
for(int i=0; i < len; i++){
  if(data[i] == target)
     bool found = true;
     break;
}  } // found is deallocated here..too early!
// check found for result of search
```

Design Pattern: Reduction

- Reduction: Combine all items in an array/list/set to produce one value (i.e. sum, check if all meet a certain criteria, etc.)
- Patten:
  - Declare a variable to hold the reduction
  - Loop over each item likely using an incrementing index
  - For each item, combine it appropriately with your reduction variable

```
// sums 'data' array of size 'len'
int sum = 0;
for(int i=0; i < len; i++){
  sum = sum + data[i];  // sum += data[i]
}
// use sum
```

Design Pattern: Reduction

- Reduction: Combine all items in an array/list/set to produce one value (i.e. sum, check if all meet a certain criteria, etc.)
- Patten:
  - Declare a variable to hold the reduction
  - Loop over each item likely using an incrementing index
  - For each item, combine it appropriately with your reduction variable

```
// checks if all elements are positive
bool allPos = true;
for(int i=0; i < len; i++){
  allPos = allPos && (data[i] > 0);
}
```

- Could also be accomplished as a search for a negative