CS103 Unit 1d – Arguments Pass-by-Value and Pass-by-Reference

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PASS-BY-VALUE, LOCAL VARIABLES, AND SCOPE

Motivating Question

- What will this code print?

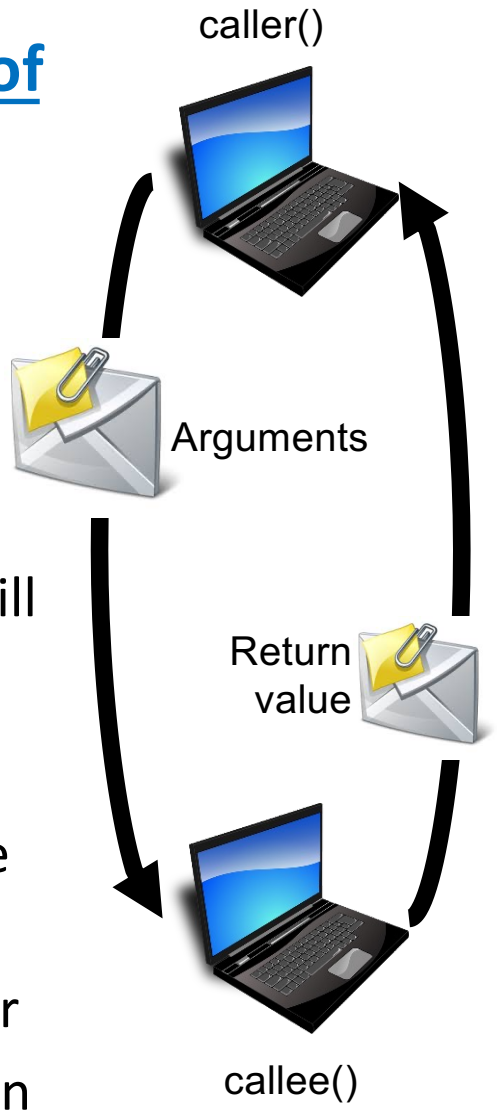
```
void dec(int);

int main()
{
  int y = 3;
  dec(y);
  cout << y << endl;
  return 0;
}

void dec(int y)
{
   y--;
}
```

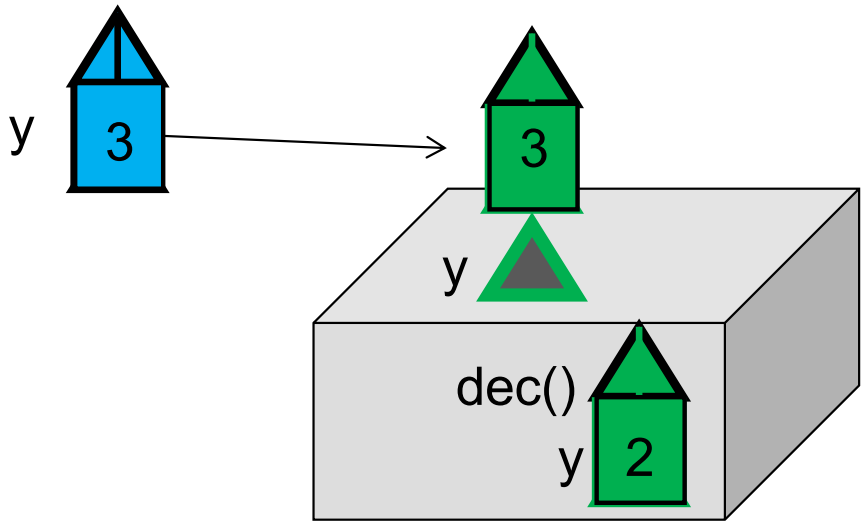
Argument Passing (Pass-by-Value)

- Passing an argument to a function **makes a copy of the argument**
  - In fancy CS-lingo, we call this **pass-by-value**
- Pass-by-value is like e-mailing an attached document
  - You still have the original on your PC
  - The recipient has a **copy** which she can modify, but it will not be reflected in your version
- Communication is essentially one-way
  - Caller communicates arguments to callee, but these are copies.
  - Any processing the callee does is not visible to the caller
  - The only communication back to the caller is via a return value.



Pass by Value (1)

- **Fact**: Function **arguments/parameters act like local variables to that function**
  - They are only in scope (only live) in the function {…} (curly braces) and then get deallocated.
- When arguments are passed a **copy** of the actual argument value (e.g. 3) is given to the function's input argument
  - So, the function is operating on a copy and that copy will die when the function ends!




```
void dec(int);
int main()
{
  int y = 3;
  dec(y);
  cout << y << endl;
  return 0;
}
void dec(int y)
{
   y--;
}
```

Pass by Value (2)

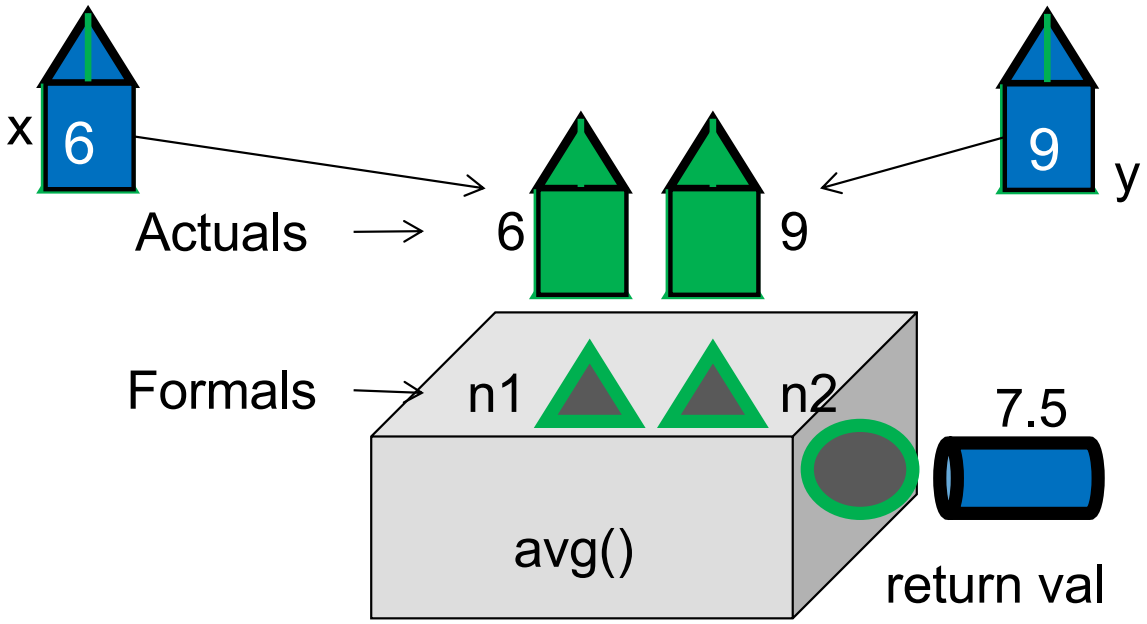
- Wait! But they have the same name, 'y'
  - What's in a name…Each function is a separate entity and so two 'y' variables exist (one in main and one in decrement it)
  - The only way to communicate back to main is via return
  - Try to change the code appropriately
- **Main Point:** Each function is a completely separate "sandbox" (i.e. is isolated from other functions and their data) and copies of data are passed and returned between them

```
void dec(int);
int main()
{
  int y = 3;
  dec(y);
  cout << y << endl;
  return 0;
}
void dec(int y)
{
   y--;
}
```

```
____ dec(int);
int main()
{
  int y = 3;
  _____________ dec(y);
  cout << y << endl;
  return 0;
}
___ dec(int y)
{
   y--;
   ____________________
}
```

Formals and Actuals (1)

- **Formal** parameters, n1 and n2
  - Placeholder names that will be used internally to the function to refer to the values passed (Similar to how generic placeholders/titles used in contracts like "CEO" or "professor" that will be assigned or replaced real value)
- **Actual** parameters, x and y
  - Actual values to be passed (i.e. the actual values to be substituted for the placeholders ("Jeff Bezos", "Mark")
  - A **copy** is made and given to function




```
#include <iostream>
using namespace std;

double avg(int n1, int n2)
{
  double sum = n1 + n2;
  return sum/2.0;
}

int main()
{
   int x=6, y = 9;  double z;
   z = avg(x,y);
   cout << "AVG is " << z << endl;
   z = avg(x, 2);
   cout << "AVG is " << z << endl;
   return 0;
}
```

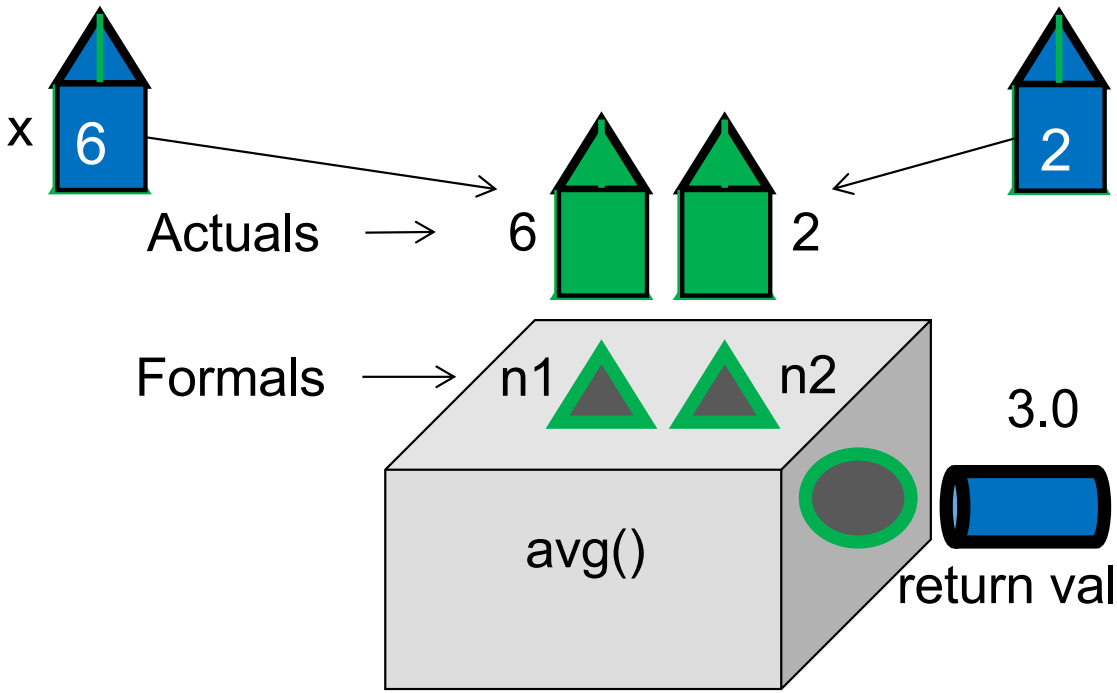
copy copy

Average
n1:
n2:
Submit

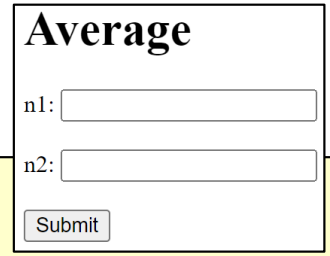
Each type is a "different" shape (int = triangle, double = square, char = circle). Only a value of that type can "fit" as a parameter..

Formals and Actuals (2)

- **Formal** parameters, n1 and n2
  - Placeholder names used inside the function
- **Actual** parameters
  - Actual values, 6 and 9 passed to n1 and n2, on the first call
  - Actual values, x and 2 passed to n1 and n2, on the second call
  - A **copy** is made and given to function



Each type is a "different" shape (int = triangle, char = square, double = circle). Only a value of that type can "fit" as a parameter.




```
#include <iostream>
using namespace std;

double avg(int n1, int n2)
{
  double sum = n1 + n2;
  return sum/2.0;
}

int main()
{
   int x=6, y = 9;  double z;
   z = avg(x,y);
   cout << "AVG is " << z << endl;
   z = avg(x, 2);
   cout << "AVG is " << z << endl;
   return 0;
}
```

copy copy

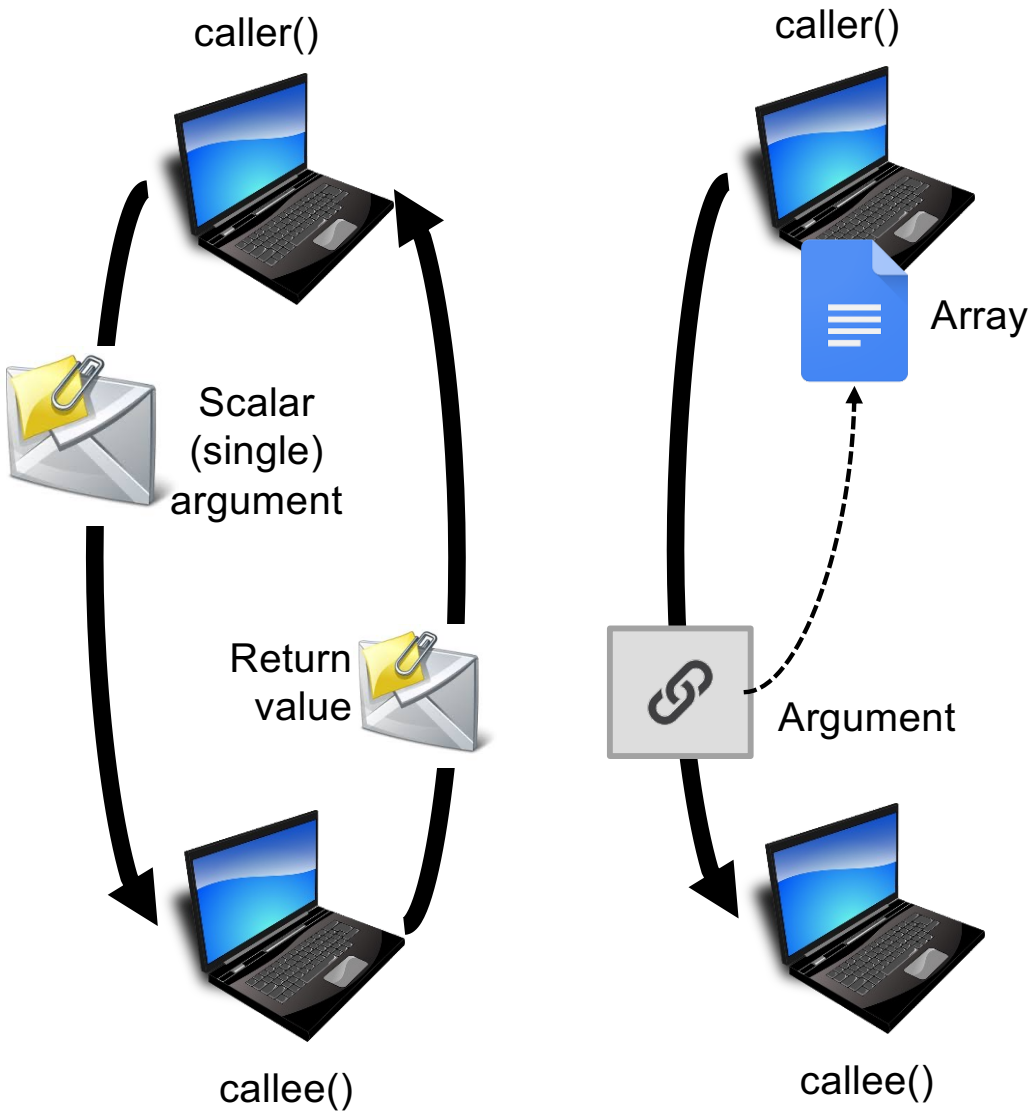
Pass-by-Value & Pass-by-Reference

- What are the pros and cons of emailing a LARGE document by:
  - Attaching it to the email
  - Sending a link (URL) to the document on some cloud service (etc. Google Docs)

- **Pass-by-value** is like emailing an attachment
  - A **copy** is made and sent
- **Pass-by-reference** means emailing a link to the original
  - **No copy is made** and **any modifications by the other party are seen by the originator**

Arrays and Pass-by-Reference

- Single (scalar) variables are **passed-by-value** in C/C++
  - Copies are passed
  - Like email attachments
- Arrays are **passed-by-reference**
  - Links (addresses) are passed
  - Like a link to a shared doc



Passing Arrays As Arguments

- Syntax:
  - **Step 1**: In the prototype and function definition:
    - Put empty square brackets **[ ]** after the **formal** parameter name if it is an array (e.g. `int data[]`) ..OR..
    - Put an ***** between the type and **formal** parameter name (e.g. `int* data`)
    - We'll prefer `int data[]` for now but `int* data` is **JUST AS VALID** and we'll learn more about it when we cover pointers)
  - **Step 2**: When you call the function, just provide the name of the array as the **actual** parameter

```
// Prototype
int init(int data[], int max_size);

int main()
{
  int vals[100];
  int len = init(vals, 100);
  // some code to process the input
  // in the vals array
  for(int i=0; i < len; i++) {
    cout << vals[i] << endl;
  }
  return 0;
}

int init(int data[], int max_size)
{
  int i=0, num;
  cin >> num;
  while( i < max_size && num != -1) {
    data[i] = num;
    i++;
    cin >> num;
  }
  return i;
}
```

Pass-by-Value / Reference

```
#include <iostream>
#include <cmath>
using namespace std;

// Function prototypes
int initScalarInt();
void initArrayOfInts(int x[], int len);
void printVals(int x1, int x2[], int x2len);

int initScalarInt()
{
    return 42;
}

// Set all array elements to 42
void initArrayOfInts(int x[], int len)
{
    for(int i=0; i < len; i++){
        x[i] = 42;
    }
}
```

```
// Function definitions
int main()
{
    int x1;
    int x2[5];

    // Print initial values
    cout << "Before setting" << endl;
    printVals(x1, x2, 5);

    // Set values
    x1 = initScalarInt();
    initArrayOfInts(x2, 5);

    // Print values after they should have been set
    cout << "After setting" << endl;
    printVals(x1, x2, 5);

    return 0;
}

void printVals(int x1, int x2[], int x2len)
{
    cout << "X1: " << x1 << endl;
    cout << "X2: ";
    for(int i=0; i < x2len; i++) {
        cout << x2[i] << " ";
    }
    cout << endl;
}
```

Passing arrays to other functions

ARRAYS AS ARGUMENTS AND ACCESSING ELEMENTS IN MEMORY

But Why Are Arrays Pass-by-Reference?

- If we used pass-by-value, then we'd have to make a copy of a potentially HUGE amount of data (what if the array had a million elements)
- To avoid copying vast amounts of data, we pass a link

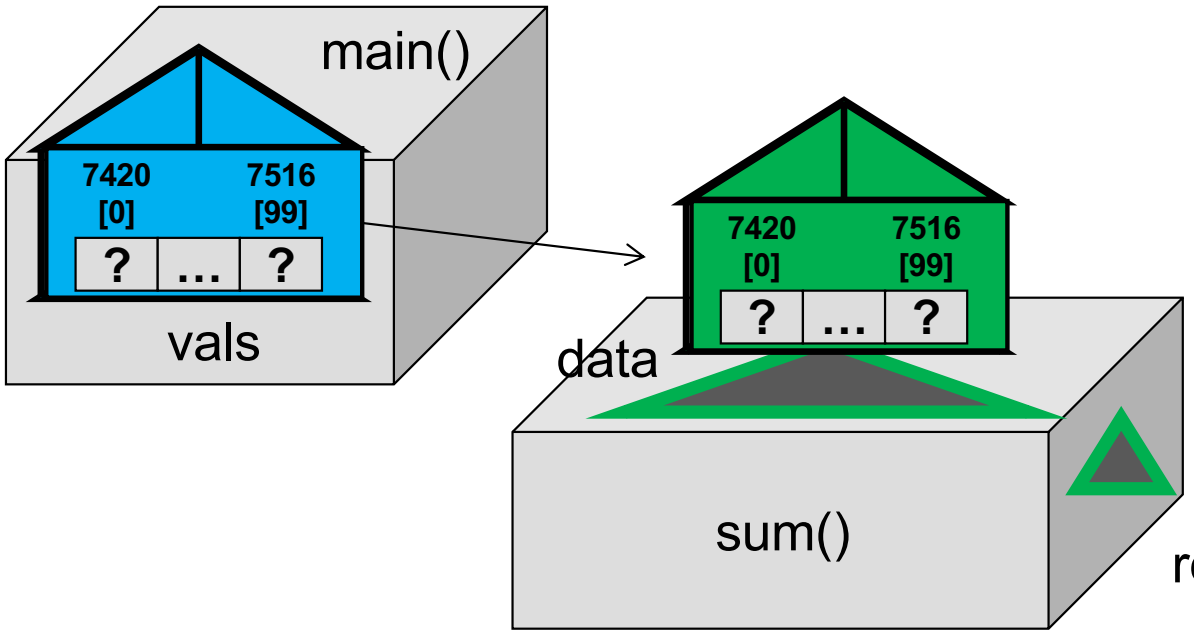
```
// Function that takes an array
int sum(int data[], int size);

int sum(int data[], int size)
{
  int total = 0;
  for(int i=0; i < size; i++){
    total += data[i];
  }
  return total;
}

int main()
{
  int vals[100];
  /* some code to initialize vals */
  int mysum = sum(vals, 100);
  cout << mysum << endl;
     // prints sum of all numbers
  return 0;
}
```

7420

7420



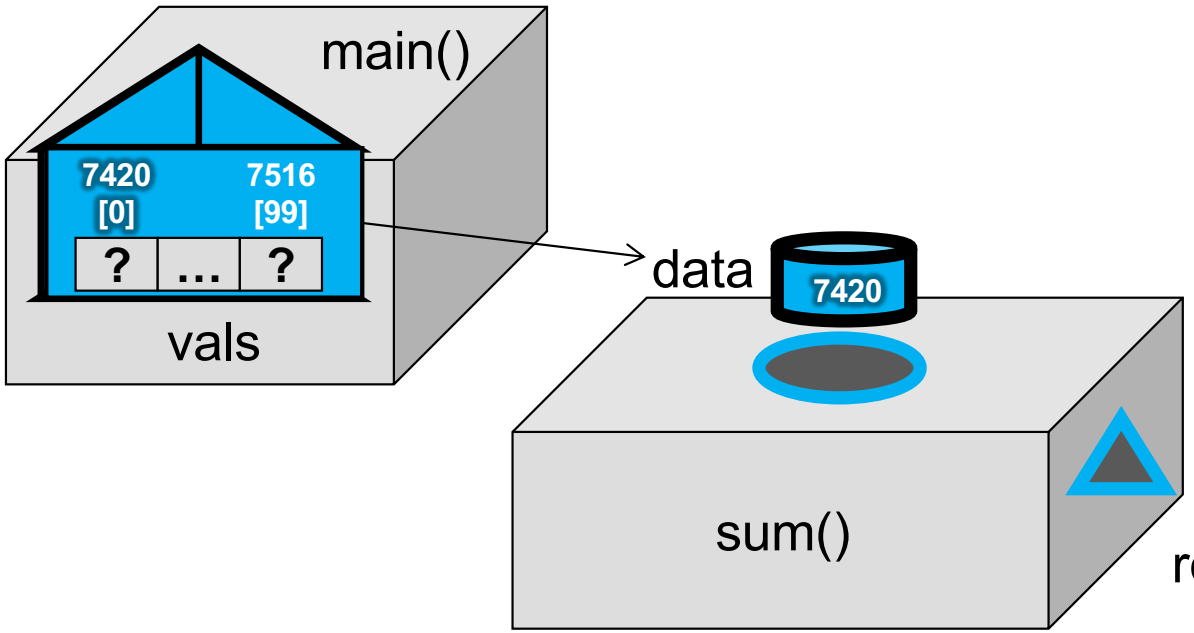
So What Is Actually Passed?

- The "link" that is passed is just the starting address of (pointer to) the array in memory (e.g. 7420).
- Once the function has the start address and the type, it will produce its own index values and be able to access the array in the caller's memory

```
// Function that takes an array
int sum(int data[], int size);
                 7420

int sum(int data[], int size)
{
  int total = 0;
  for(int i=0; i < size; i++){
    total += data[i];
  }
  return total;
}

int main()
{
  int vals[100];
  /* some code to 7420 ialize vals */
  int mysum = sum(vals, 100);
  cout << mysum << endl;
     // prints sum of all numbers
  return 0;
}
```



To access an element in an array, we need 3 pieces of info:

1. **Start address of the array**
2. **Index/offset**
3. **Type of elements in the array (really the size of that type)**

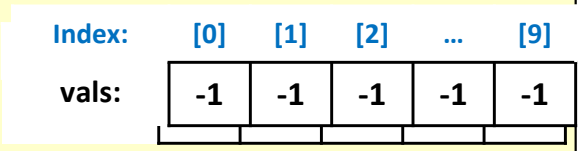
Arrays And Pass-by-Reference

- Arrays are **passed-by-reference**
  - Links (addresses) are passed
    - **These links are actually memory addresses where the array starts.**
    - Using these addresses, any function can go to those locations and modify the data (array) from another function
  - Thus, changes to the array by a function are visible upon return to the caller
  - In this example, `nums` and `vals` refer to the **same** array

```
void init(int data[], int size);

int main()
{
  int vals[10];
  init(vals, 10);
  cout << vals[2] << endl;
     // prints -1
  return 0;
}

void init(int nums[], int size)
{  // nums is really a link to vals
   for(int i=0; i < size; i++){
     nums[i] = -1;
     // changing vals[i]
   }
}
```



Strange Question

- The first house on the on the block of a street has address 7420.
- How many houses are on the block?

- Look at the memory to the right. An array starts at address 7420. How many elements are in that array?
- Having the start address doesn't allow us to know how big the array is.

- We must also track / pass the **size**!

Address	Memory Data	
7412	a184beef	07818821
array 7420	5621930c	e400cc33
7428	a184beef	07818821
7436	5621930c	e400cc33
...	...	

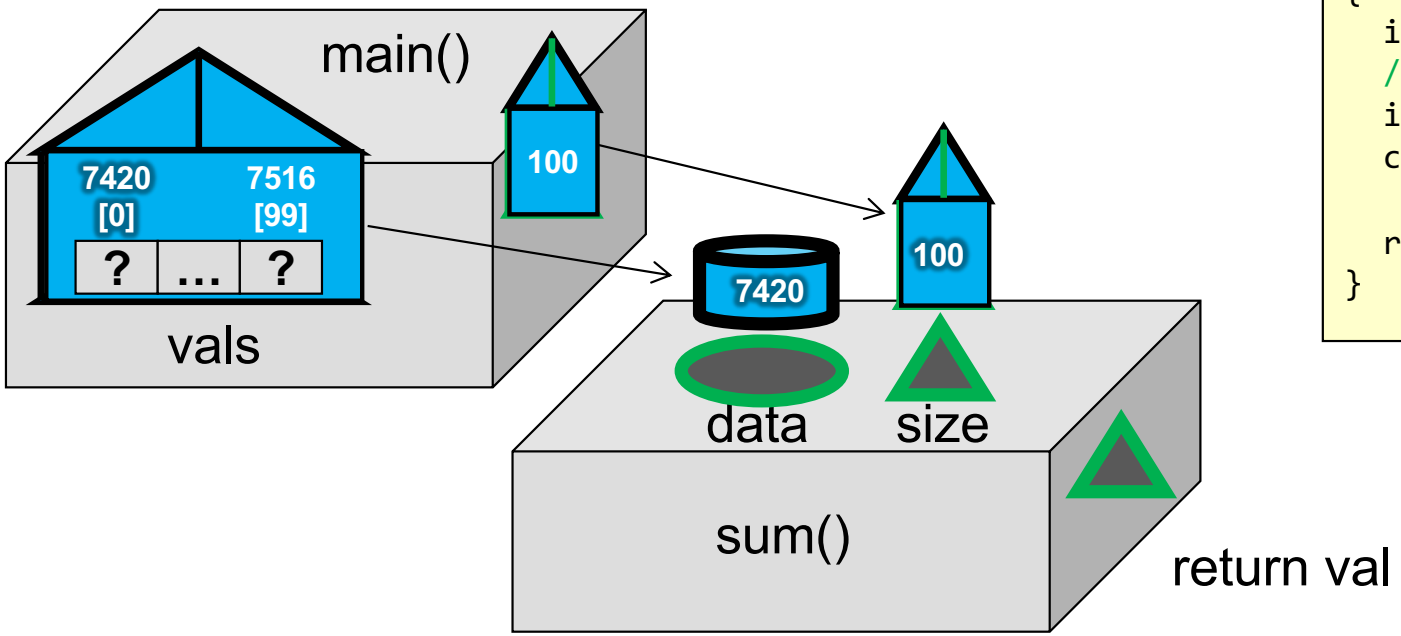
Arrays in C/C++ vs. Other Languages

- Notice that if sum() only has the start address it **would not know** how big the array is
- **Unlike Java** or other languages where you can call some function or access some property to give the size of an array, **C/C++ require you to track the size yourself in a separate variable and pass it as a secondary argument**

```
// Function that takes an array
int sum(int data[], int size);

int sum(int data[], int size)
{
  int total = 0;
  for(int i=0; i < size; i++){
    total += data[i];
  }
  return total;
}

int main()
{
  int vals[100];
  /* some code to initialize vals */
  int mysum = sum(vals, 100);
  cout << mysum << endl;
     // prints sum of all numbers
  return 0;
}
```

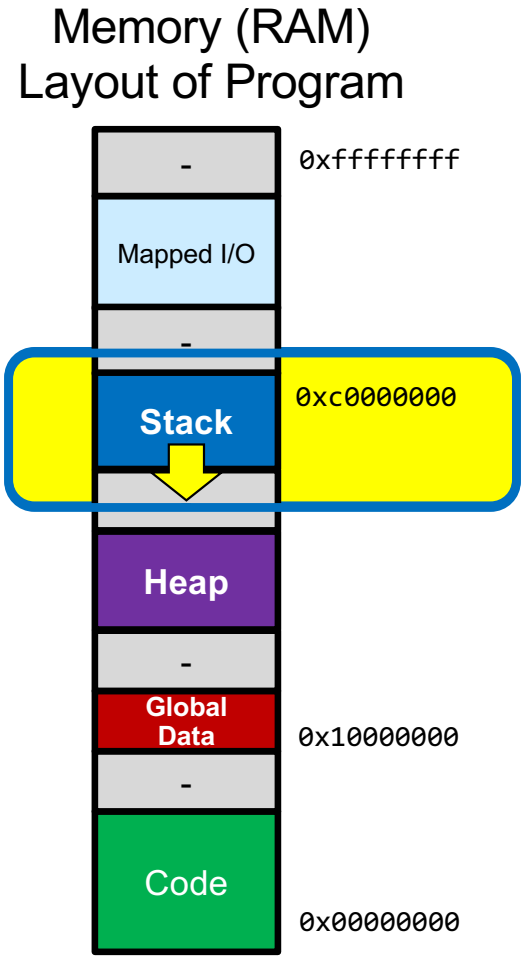


Understanding how functions utilize the **stack** area of computer memory

PASSING ARGUMENTS: A DEEPER LOOK

Memory Organization

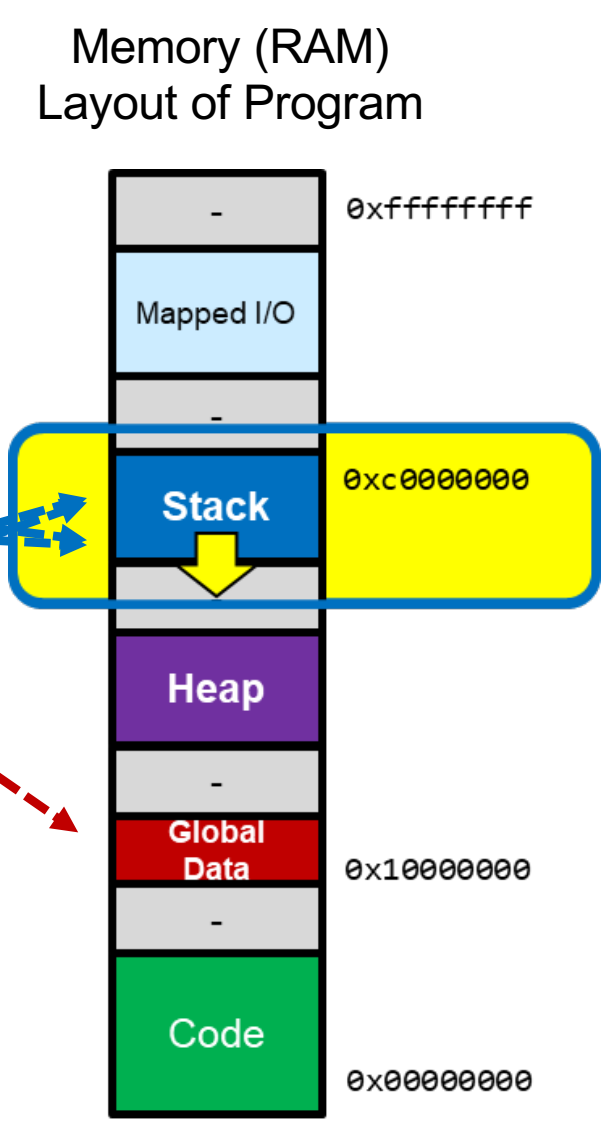
- 32-bit address range (`0x0 to 0xffffffff`)
  - Note **`0x`** indicates a hexadecimal number
- **Code** usually sits at lower addresses
- **Global** variables/data somewhere after code
- **Heap**: Area of memory that can be allocated and de-allocated during program execution (i.e. dynamically at run-time) based on the needs of the program
  - More in a few lectures
- **Stack (our focus):** Memory for all information related to each running instance of a **function**
  - Arguments to the function
  - Local variables
  - Return link (where in the code to return)



Mapping of Info to Memory

```
#include <iostream>
#include <algorithm>
#include <cmath>
using namespace std;
int timesCalled = 0;  // global variable

int factorial(int n)
{
    int f = 1;
    for(int i = 1; i <= n; i++) {
        f *= i;
    }
    timesCalled++;
    return f;
}
int main() {
  int n;
  cin >> n;
  int res = factorial(n);
  cout << res << " " << timesCalled << endl;
  return 0;
}
```



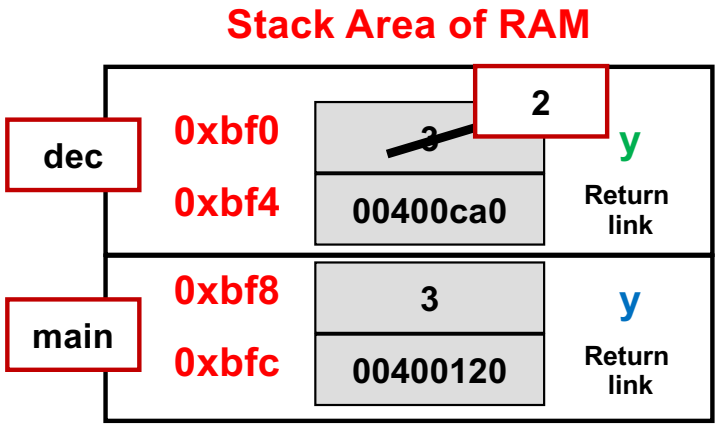
Understanding the Stack and Pass-by-Value

- Each program allocates an area of memory known as the **system stack** where all data related to the function is stored including:
  - **Local variables**
  - **Arguments to the function**
  - Return link (where to return) to the calling code
- Each time a function is called, the computer **allocates** memory for that function on the top of the stack and creates a link for where to return
- When a function returns/ends, that memory is **deallocated** (destroying all arguments and local variables) and control is returned to the function now on top

```
// Prototype
void dec(int);

int main()
{
  int y = 3;
  dec(y);
  cout << y << endl;
  return 0;
}

void dec(int y)
{
   y--;
}
```



Understanding the Stack and Pass-by-Value

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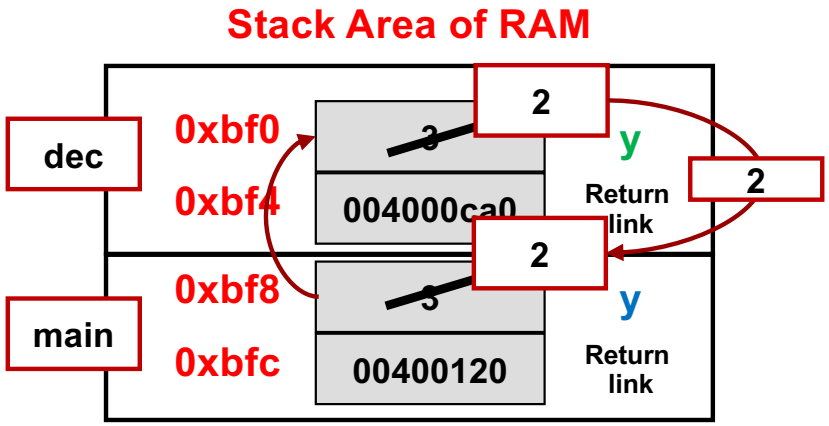
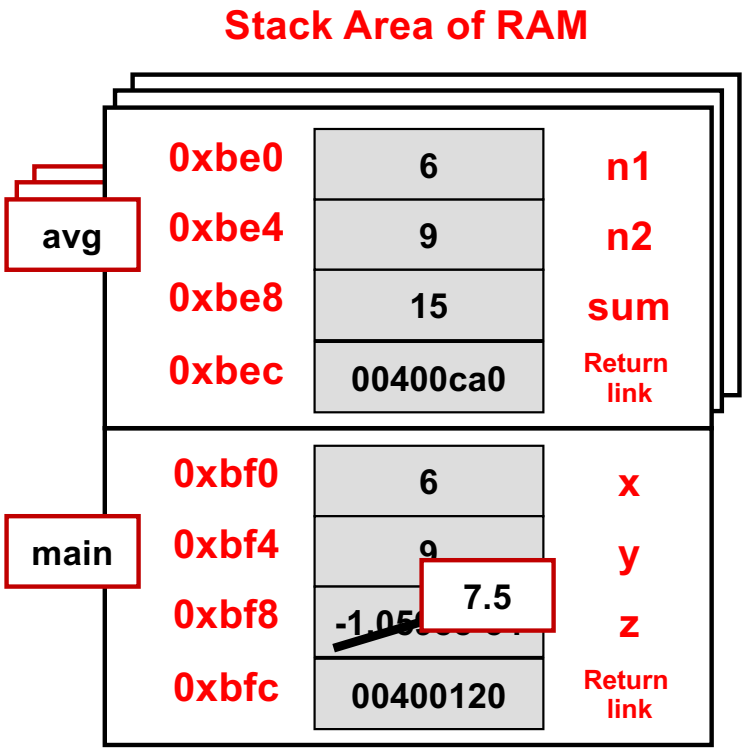
- Each time a function is called, the computer **allocates** memory for that function on the top of the stack and creates a link for where to return
- When a function returns/ends that memory is **deallocated** (destroying all arguments and local variables) and control is returned to the function now on top

```
// Prototype
void dec(int);

int main()
{
  int y = 3;
  y = dec(y);
  cout << y << endl;
  return 0;
}

int dec(int y)
{
   y--;
   return y;
}
```



Another Example

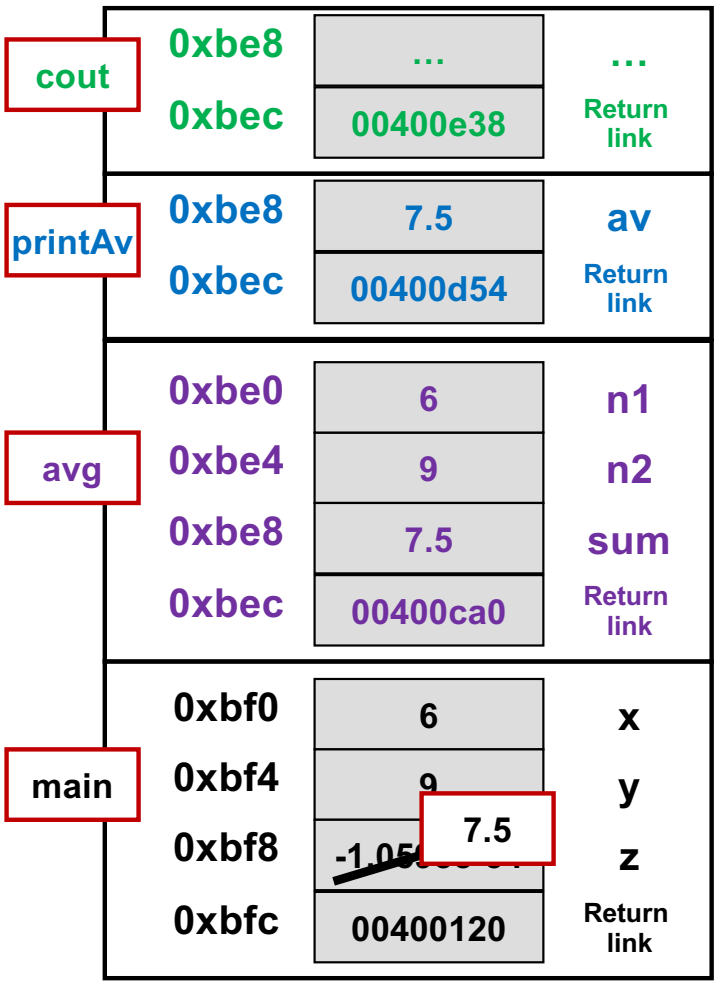
- Each program allocates an area of memory known as the **system stack** where all data related to the function is stored including:
  - **Local variables**
  - **Arguments to the function**
  - Return link (where to return) to the calling code




```
#include <iostream>
using namespace std;

double avg(int n1, int n2); // Prototype

int main()
{
   int x=6, y = 9;  double z;

   z = avg(x,y);
   cout << "AVG is " << z << endl;

   z = avg(x, 2);
   cout << "AVG is " << z << endl;
   return 0;
}

double avg(int n1, int n2)
{
  double sum = n1 + n2;
  return sum/2.0;
}
```

Scope and Stack Example

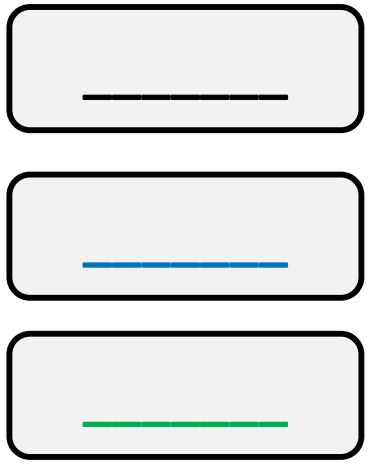
- The **scope** of local variables and arguments are only for the lifetime of the function in which they live
- One function cannot access the local variables of another



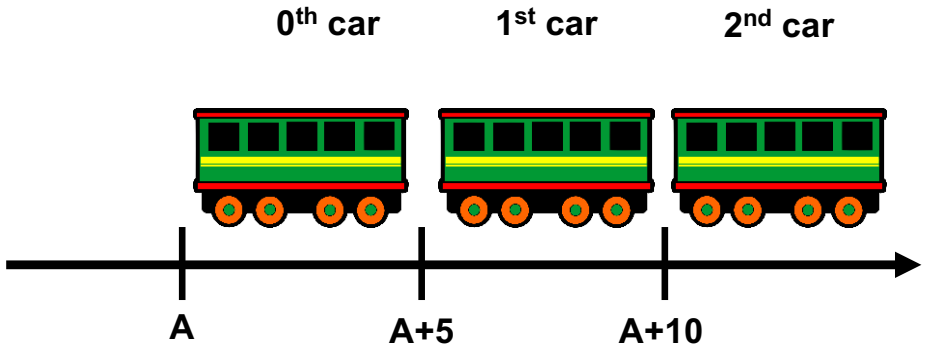

```
#include <iostream>
using namespace std;

double avg(int n1, int n2); // Prototype
void printAv(double x);     // Prototype

int main()
{
   int x=6, y = 9;  double z;

   z = avg(x,y);

   z = avg(x, 2);

   return 0;
}

double avg(int n1, int n2)
{
  double sum = (n1 + n2)/2.0;
  printAv(sum);
  return sum;
}

void printAv(double av)
{
  cout << "Average is " << av << endl;
}
```

A Quick Tangent: Array Element Addresses

- Consider a train with many copies of the same car
  - The "0th" car starts at **point A** on the number line
  - Each car is **5 meters** long
- Write an arithmetic expression for where the **i-th car** is located. (At what meter on the number line does it start?)
- Suppose an array of integers starts at memory address A, write an expression for where the **i-th integer** starts?
- Suppose an array of doubles starts at memory address A, write an expression for where the **i-th double** starts?

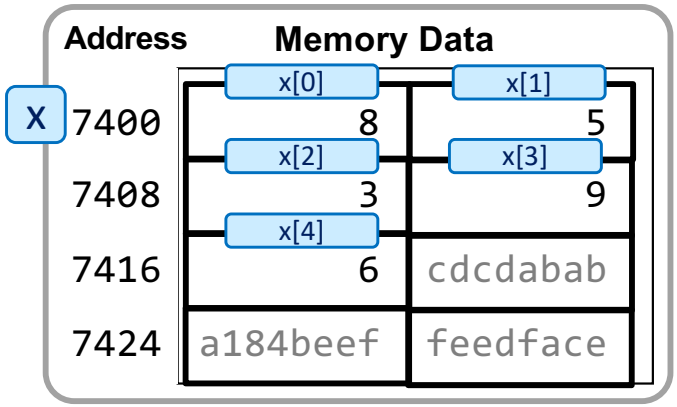


Formula for address of i-th element:



Formula for Addressing Array Elements

- Assume a 5-element int array
  - `int x[5] = {8,5,3,9,6};`
- **Fun Fact 3 (after Unit 0's Fact 1 & 2):** Using the **name of an array by itself (e.g. x)** w/o square brackets, evaluates to the **starting address** in memory of the array (i.e. address of 0th entry).
- When you access x[2], the CPU uses x (to know the starting address) and adds the product of the index, 2, times the size of the data type (i.e. int = 4 bytes)
  - x[2] => int. @ address 7400 + 2*4 = 7408
  - x[3] => int. @ address 7400 + 3*4 = 7412
  - x[i] @ start address of array + i * (size of int)
- **Recall**: C/C++ does NOT perform bounds checking to stop you from attempting to access an element beyond the end of the array
  - x[6] => int. @ address 7400 + 6*4 = 7424 (Garbage!!)



To access an element in an array, we need 3 pieces of info:

1. **Start address of the array**
2. **Index/offset**
3. **Type of elements in the array (really the size of that type)**

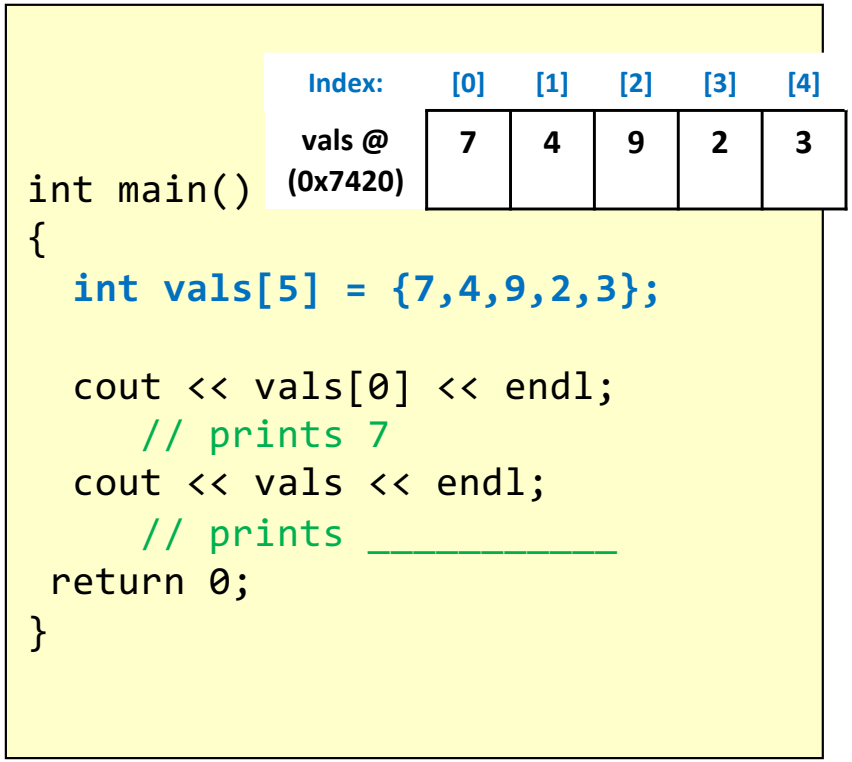
Formula: `start_addr + i*data_size`

Fun Fact 3: If you use the **name of an array (e.g. x)** w/o square brackets it will evaluate to the **starting address** in memory of the array (i.e. address of 0th entry)

Fun Fact 3b: Fun Fact 3 usually appears as one of the first few questions on the midterm.

Array Elements vs. Array Names

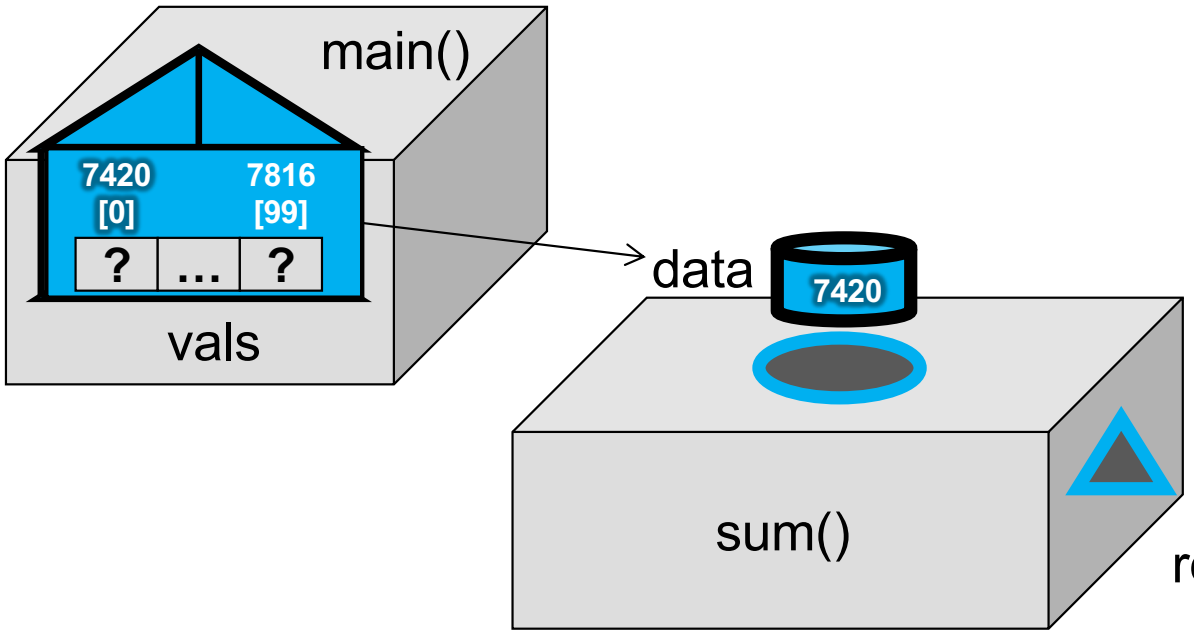
- **In C/C++ using an array name without any index evaluates to the starting address of the array**
- **Example:**
  - **`vals[0]` yields data**
  - **`vals` yields an address**



Recall: Passing Arrays

- The "link" that is passed is just the starting address of (pointer to) the array in memory (e.g. 7420).
- Once the function has the start address and the type, it will produce its own index values and be able to access the array in the caller's memory

```
// Function that takes an array
int sum(int data[], int size);
                7420

int sum(int data[], int size)
{
  int total = 0;
  for(int i=0; i < size; i++){
    total += data[i];
  }
  return total;
}

int main()
{
  int vals[100];
  /* some code to 7420 ialize vals */
  int mysum = sum(vals, 100);
  cout << mysum << endl;
     // prints sum of all numbers
  return 0;
}
```

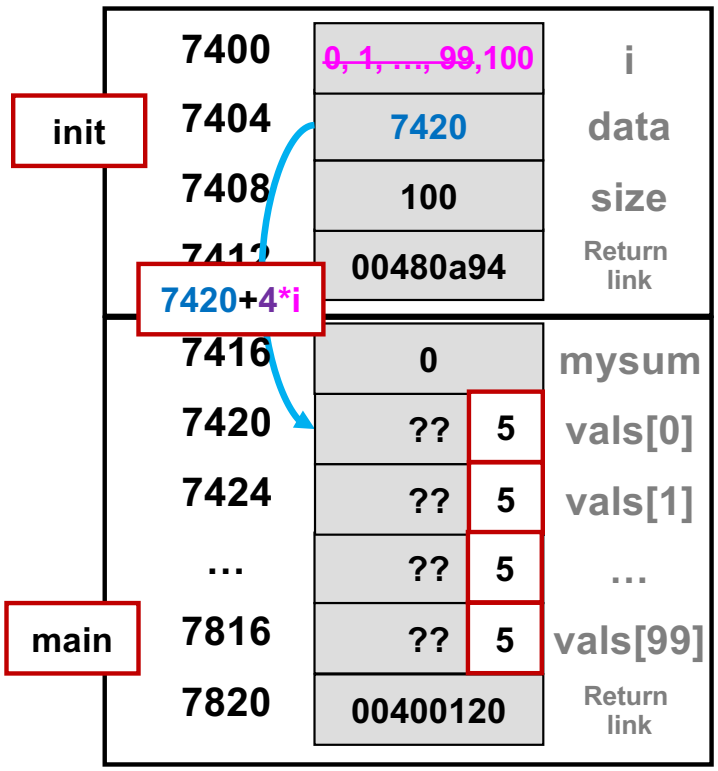


To access an element in an array, we need 3 pieces of info:

1. **Start address of the array**
2. **Index/offset**
3. **Type of elements in the array (really the size of that type)**

Stack View of Passing Arrays

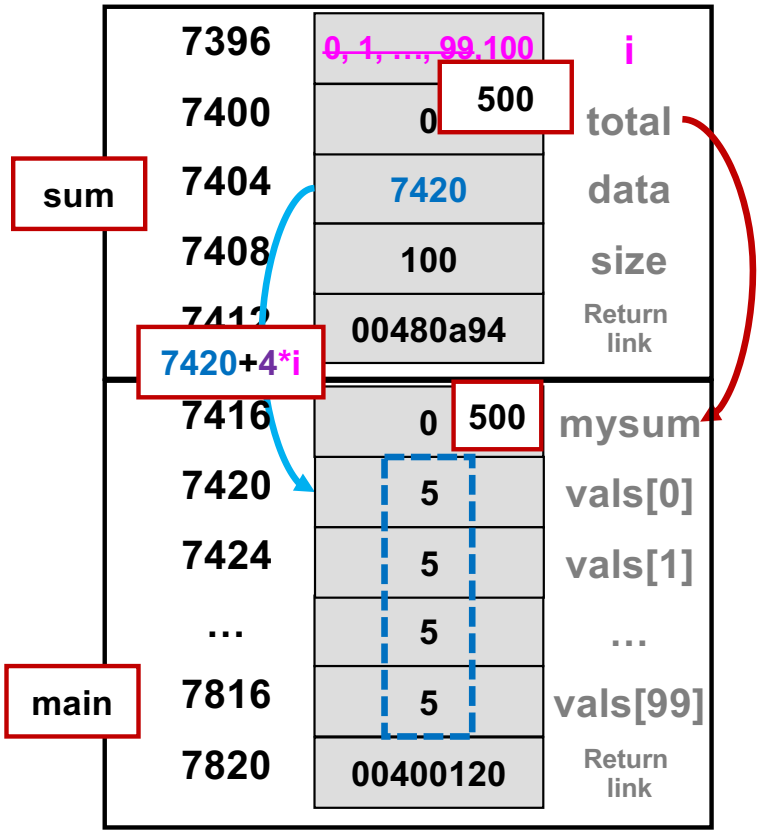
- The function receives the starting address of the array which it can use along with the type (e.g. `int`) and index to access the appropriate values from main's stack area of memory.




```
void init(int data[], int size);
int sum(int data[], int size);
int main()
{
  int vals[100], mysum = 0;

  init(vals, 100);
  mysum = sum(vals, 100);
  cout << mysum << endl;

  return 0;
}

void init(int data[], int size)
{
  for(int i=0; i < size; i++){
     data[i] = 5;
  }
}
```

Stack View of Passing Arrays

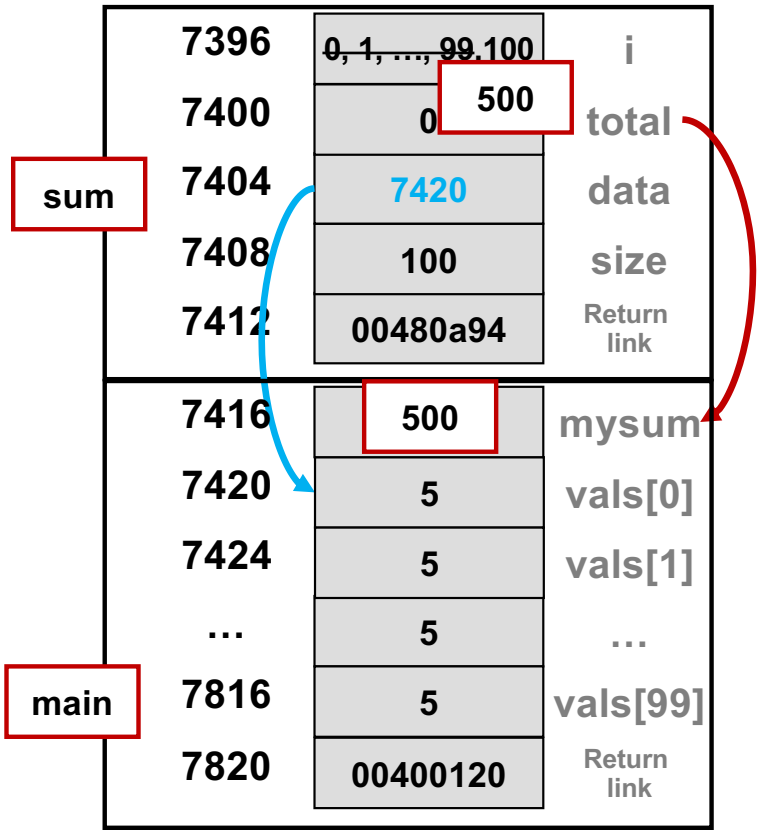
- The function receives the starting address of the array which it can use along with the type (e.g. `int`) and index to access the appropriate values from main's stack area of memory.




```
void init(int data[], int size);
int sum(int data[], int size);

int main()
{
  int vals[100], mysum = 0;

  init(vals, 100);
  mysum = sum(vals, 100);
  cout << mysum << endl;

  return 0;
}
int sum(int data[], int size)
{
  int total = 0;
  for(int i=0; i < size; i++){
    total += data[i];
  }
  return total;
}
```

Why Empty Brackets

- Why don't we just supply the array size in the formal argument?
  - Now we can only process arrays of size 100. We'd like our functions to be more general and handle any size array
  - C/C++ doesn't do bounds checking anyway, so what good would writing 100 be?

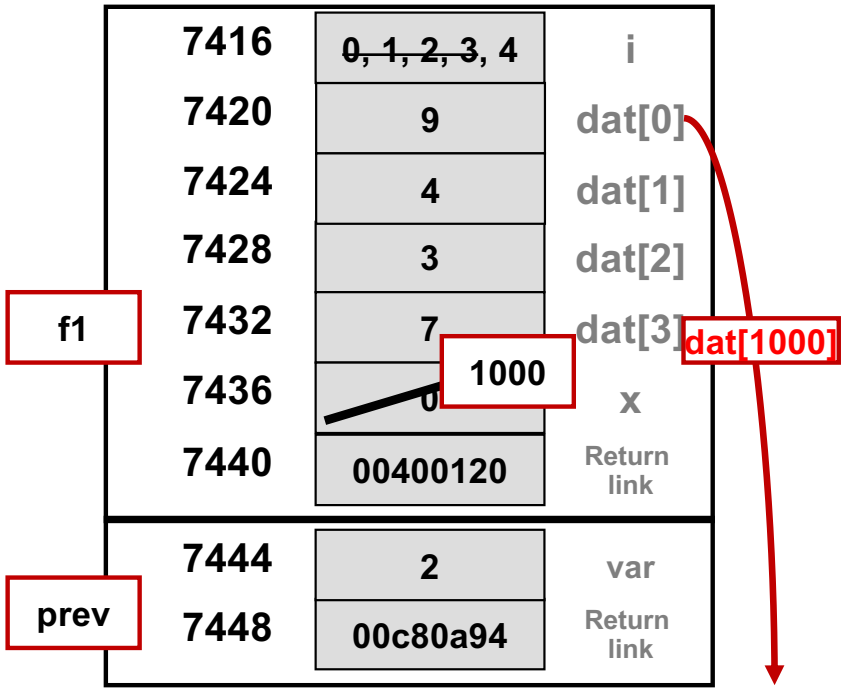



```
int sum(int data[100], int size);

int sum(int data[100], int size)
{
  int total = 0;
  for(int i=0; i < size; i++){
    total += data[i];
  }
  return total;
}

int main()
{
  int vals[100];
  /* some code to initialize vals */
  int mysum = sum(vals, 100);
  cout << mysum << endl;
     // prints sum of all numbers
  return 0;
}
```

(Lack of) Array Bounds Checking

- C++ does **NOT** bounds check the index used to access an element
  - It will simply treat all of memory as part of the array (i.e. larger positive indices go past the end of the array while negative offsets are before the array start)
  - Thus, allowing you to read and write data you shouldn't (including variables from your own function or another function since local variables live on the stack)
  - This issue is a common exploit by hackers (more in future courses like CS 356)

```
int f1()
{
  int dat[4], x=0;

  for(int i=0; i <= 4; i++){
     cin >> dat[i];  // 9, 4, 3, 7, 1000
  }
  // using i=4 overwrites 'x'
  cout << x << endl;
     // 1000 would print, not 0.
  cout << dat[x] << endl;
     // likely segmentation fault
  return 0;
}
```



Array Summary

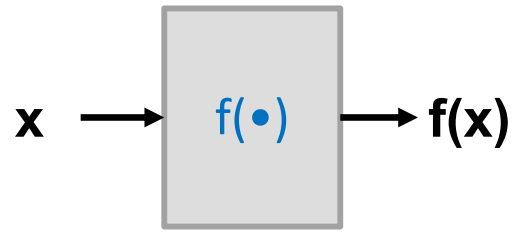
- Arrays must be declared with a **FIXED** size (cannot use a variable for its length)
  - `GOOD: int data[50];`
  - **BAD**: `int data[n];`
- After declaring an array, C/C++ only "remembers" the **starting address** of the array and the **type** of data it holds (to know the **data size**)
  - Which is all it needs to know to access any element using the formula: `start_addr + i*data_size`
- C/C++ do NO bounds checking
  - Will simply apply the formula above to **WHATEVER** index you provide or calculate
  - Most common source of a program crash (and also security vulnerabilities). If your program crashes in CS 103, suspect a bad array access

Using arrays as a lookup table

LOOKUP TABLES

Motivation and Approaches

- Problem Statement: Given an input, x, convert it to an output using some function, f(x)
- Possible approaches
  - Use an arithmetic relationship, when the relationship can be easily generalized
  - Break it into cases with if statements when there are a reasonable number of cases
- What if there is little pattern or many cases?
- Consider use of an **array** as a **"look-up table"**



x:	0	1	2	3	4
f(x):	1	3	5	7	9

f(x) = _____

x:	0	1	2	3	4	5
f(x):	1	1	1	2	2	2

f(x) = __, if _____
f(x) = __, otherwise

x:	0	1	2	3	4	5
f(x):	4	1	0	2	5	3

f(x) = _____

Arrays as Look-Up Tables

- **Look-up Table Idea**: Store pre-computed results in an array and then "look-up" the desired result using the input as the array index
- Can extend this to process many inputs (an array of inputs)
  - Suppose an instructor with 8 students gives a quiz worth 10 points and we use the customary (>90% = A, 80% = B, 70% = C, 60% = D, <60% = F) and we want to map the points to the letter grade. How would you do it?

x:	0	1	2	3	4	5
f(x):	4	1	0	2	5	3

```
int main()
{
  int myf[] = {4, 1, 0, 2, 5, 3};
  int x;
  cin >> x;
  cout << myf[x] << endl;
  return 0;
}
```

Problem from Previous Slide

```
int main()  {
  int scores[8] = {9,7,10,9,8,4,6,8};
  char grades[11] =

 {'F','F','F','F','F','F','D','C','B','A','A'};
  for(int i=0; i < 8; i++){
    // output the letter grade for each score
    cout << "Score: " << scores[i] << " => "

         << "Grade: " << ____________________
         << endl;
  }
  return 0;
}
```

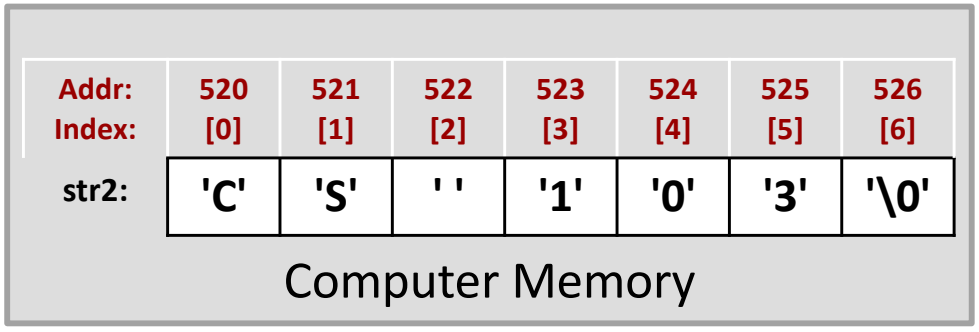
Grade Mapping Problem

C-STRINGS, COUT, AND CIN

Character Arrays and Strings (1)

- Recall that in C/C++ string constants (the text in between " ") are just character arrays
  - Each character consumes 1 element in the array
  - Ends with the null character (e.g. 0 decimal or '\0' ASCII)
- This approach of using an array of `char`'s to store a string is referred to as a **C-String** because there was no `string` type in C (i.e. before C++)

```
#include <string>
using namespace std;
int main()
{
  char str1[3] = {'C', 'S', '\0'};
  // For char arrays easier to use ""
  char str2[7] = "CS 103"
  /* Initializes the array to "CS 103"*/

  cout << str1 << endl;    // prints "CS"
  cout << str2 << endl;    // prints "CS 103"

  str2[5] = '4';
  cout << str2 << endl;    // prints "CS 104"

  cin >> str2; // get a new string from
               // the user (suppose user
               // types "hello"
  cout << str2;
}
```

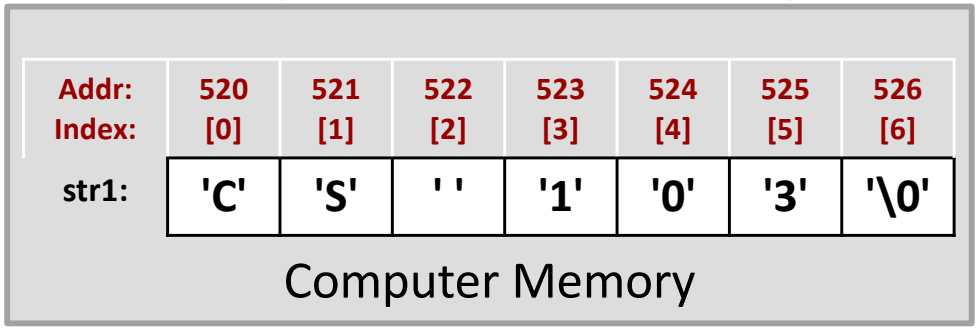


Program Output:

```
CS
CS 103
CS 104
hello
```

Character Arrays and Loops

- How many things can a computer do at a time?
- To printout a string/character array, we'd have to print one character at a time!
- But C/C++ treats character arrays specially. `cout` has a loop inside its code to print strings/character arrays.
- Though not shown, `cin` also has a loop inside to input a string.
- We say `cout` and `cin` have a **special relationship with character arrays.**




```
#include <string>
using namespace std;
int main()
{
  char str1[7] = "CS 103"
  /* Initializes the array to "CS 102"*/

  // Usually in C/C++ we must use a loop to do
  // many operations
  for(int i=0; str[i] != '\0'; i++) {
    cout << str[i];
  }
  cout << endl;

  // but cout has its own loop so you don't
  // have to write the loop above but just
  // what you see below.
  cout << str1 << endl;    // prints "CS 102"
}
```

Program Output:

```
CS 103
CS 103
```

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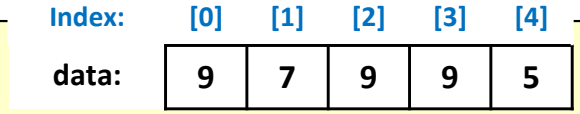
cout's Special Relationship with Character Arrays

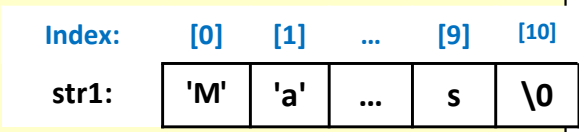
- To print out all elements of **any array type *OTHER than a character array*** (i.e. `int`, `double`, `bool`, etc.) you must **write your OWN loop** (i.e. because computers can only do 1 thing at a time)
- But for **character arrays**, you can just give `cout` the name of the array and it will use its **own INTERNAL loop** to print out all characters for you
  - So, internally it is actually looping over the characters so you don't have to
  - It just assumes when you give it a character array that you WANT it to print out all the characters in the array
- Thus, we say **`cout`** treats **character** arrays specially




```
int main()
{
  int data[5] = {9, 7, 8, 9, 5};
  char str1[] = "Many chars";
  // right way to print int array contents
  for(int i=0; i < 5; i++){
    cout << data[i] << " ";
  }
  cout << endl;

  // doesn't work for an int, double
  // or any other type of array
  cout << data << endl;

  // cout treats char. arrays specially
  cout << str1 << endl;
}
```



Program Output:

```
9 7 8 9 5
0x7fffce40
Many chars
```

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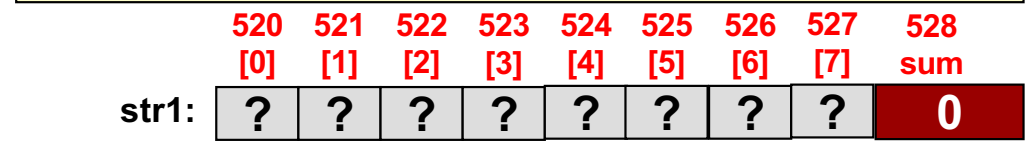
cin's Special Relationship with Character Arrays

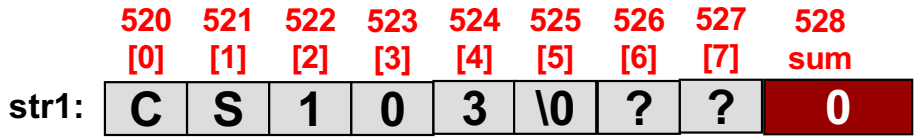
- To get input for all elements of an array type *OTHER than character arrays* (i.e. `int`, `double`, etc.) you must **write your OWN loop**
- But for character arrays, you can just give `cin` the name of the array and it will use its **own INTERNAL loop** to receive all characters the user types and store them sequentially in the array
  - So, internally it is actually looping over the characters so you don't have to
  - It just assumes when you give it a character array that you WANT it to get a full string (stopping at the next space)
- **`cin`** treats **character** arrays specially

```
int main()
{
  int data[5]; //5 garbage values to start
  char str1[8];//8 garbage values to start
  int sum = 0;
  // doesn't work for an int, double
  // or any other type of array
  cin >> data;  // won't even compile

  // right way to get int array contents
  for(int i=0; i < 5; i++){
    cin >> data[i];
  }

  // cin treats char. arrays specially
  cin >> str1;
}
```





A Problem with `cin` and Character Arrays

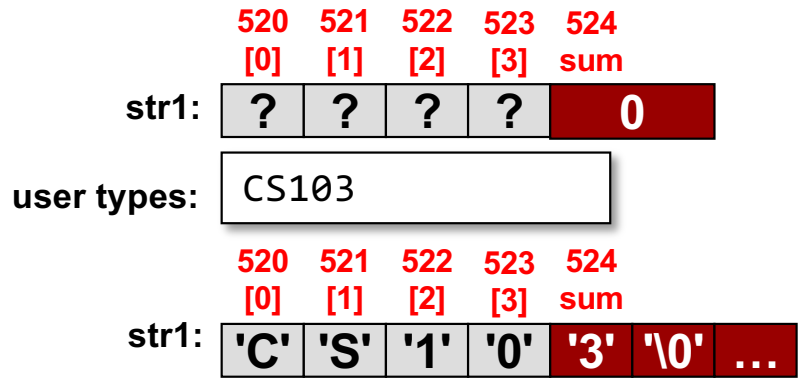
- What if the user types in **TOO** much (*more characters than our array has room to store*)?
- `cin` will not stop! It will keep storing the characters the user types, overwriting whatever data and variables came after the array
- **Warning**: `cin` does not CHECK that the string typed by the user will fit in the array; instead it simply **overwrites memory leading to undefined (bad) behavior!**

- **C++ strings fix this issue, allocating more space based on what is typed.**

```
int main()
{
  char str1[4];
  int sum = 0;
  // What if user types in "CS102"
  cin >> str1;

  cout << sum << endl;
  // won't see 0 because sum was modified
  // when cin received the string that was
  // too long!

  string s2;
  cin >> s2;
  // works regardless of user input length
}
```



Exercises

- **Cipher**: Using an array as a Look-Up Table
  - 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

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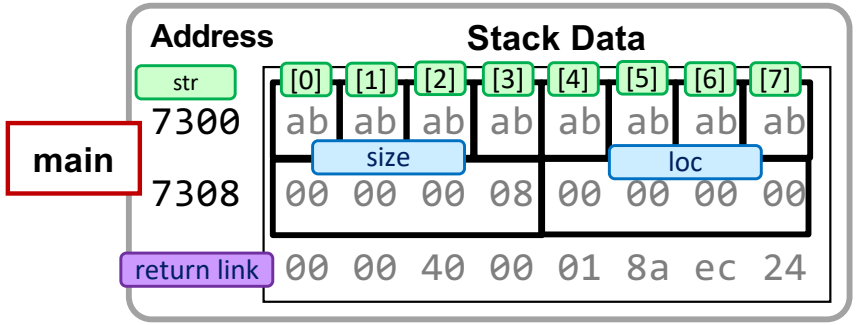
Input Buffer Overflow [Only if Time]

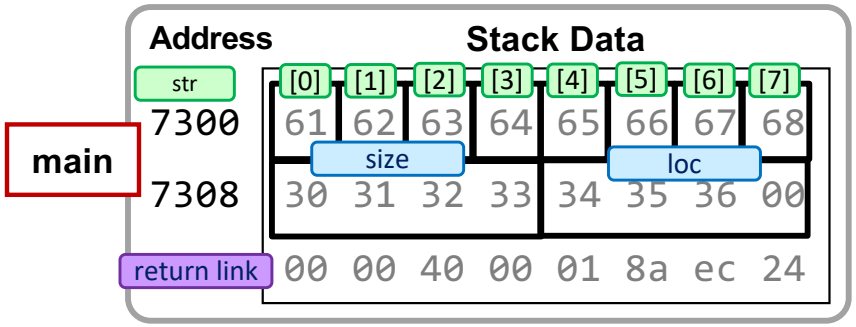
- Depending on user input, this program will likely crash.

```
$ ./prog1
abcdefgh0123456
```

Stack before execution of `cin >> str`.



Stack after execution of `cin >> str`.



Find location of first capital letter in text

```
#include <iostream>
#include <cctype>
using namespace std;
int main()
{
  char str[8];
  const int size = 8
  int loc = 0;

  // User types "abcdefgh0123456"
  cin >> str;

  // size may now be garbage (not 8)
  for( int i=0; i < size; i++){
    if( isupper(str[i]) )
      { loc = i; break; }
  }
  // You'll be lucky to even get here
  cout << loc << endl;
  return 0;
}
```

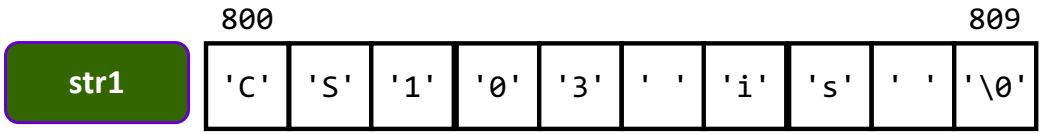
NULL Terminated character arrays

C-STRINGS (CHARACTER ARRAYS)

C-Strings

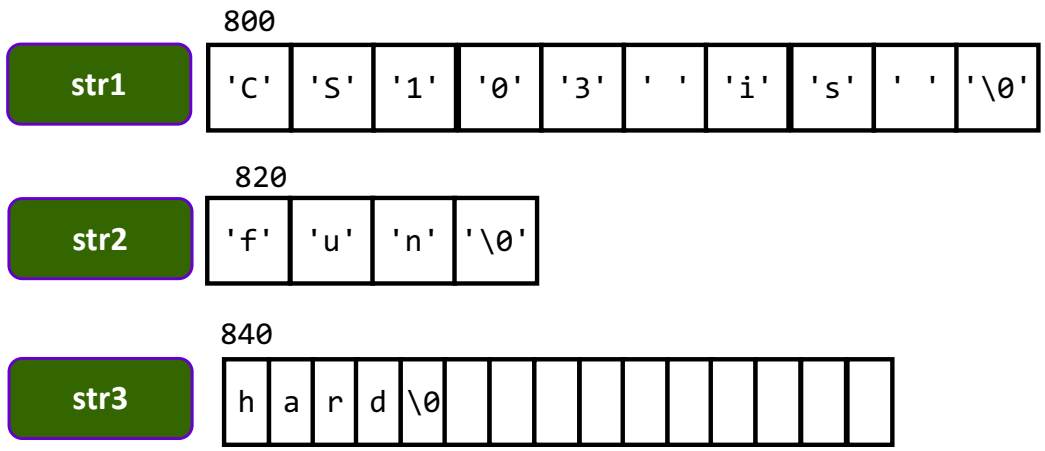
- In C:
  - strings were not a first-class type (i.e. no `string` type)
  - strings were simply character arrays (`char [ ]`) **terminated by the null character** (0 dec. = '\0' ASCII)
  - These were known as C-Strings
- No operations/operators other than typical array operations are provided
  - **No** comparison (== or !=)
  - **No** assignment/copy (=)
  - **No** append/concatenate (+)

```
int main()
{
  char str1[] = "CS103 is ";
  char str2[] = "fun";
  char str3[15];

  cin >> str3;   // user enters "CS103"

  // What is this actually comparing?
  if(str3 == str2)
    { cout << "Match" << endl; }

  str3 = str1;
  str3 += str2;

  cout << str3 << endl;
  return 0;
}
```



Errors

```
int main()
{
  char str1[] = "CS103 is ";
  char str2[] = "fun";
  char str3[15];

  cin >> str3;  // user enters "CS103"

  // What is this actually comparing?
  if(str3 == str2)
    { cout << "Match" << endl; }

  // Intuitively this makes sense but
  // will not compile in C/C++. Using your
  // knowledge of types and other info,
  // what is this actually attempting to do.
  str3 = str1;
  str3 += str2;

  cout << str3 << endl;
  return 0;
}
```



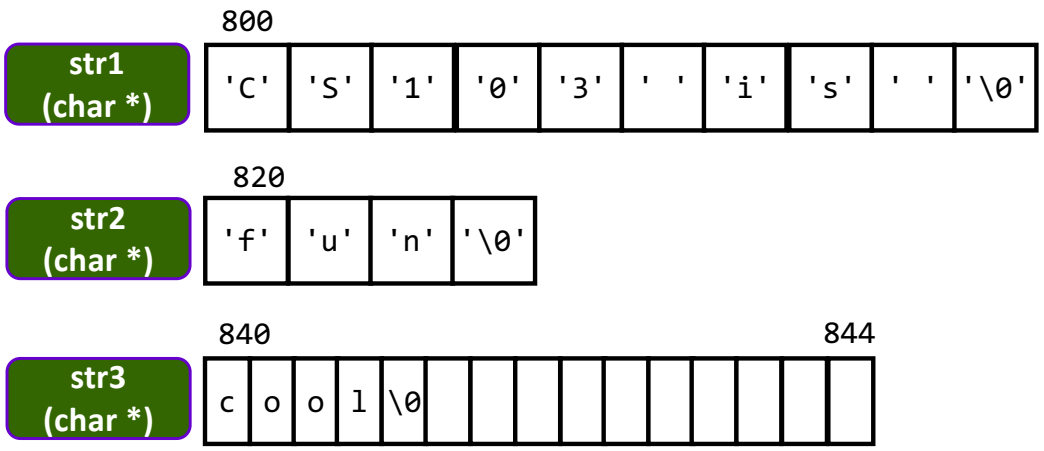

```
main.cpp:15:13: warning: comparison between two arrays is deprecated;
if(str3 == str2) { cout << "Match" << endl; }
~~~~ ^ ~~~~ main.cpp:15:13: warning: array comparison always evaluates to false

main.cpp:20:10: error: array type 'char[15]' is not assignable
str3 = str2;
~~~~ ^
main.cpp:21:10: error: invalid operands to binary expression ('char[15]' and
'char[7]')
str3 += str2;
~~~~ ^ ~~~~
```

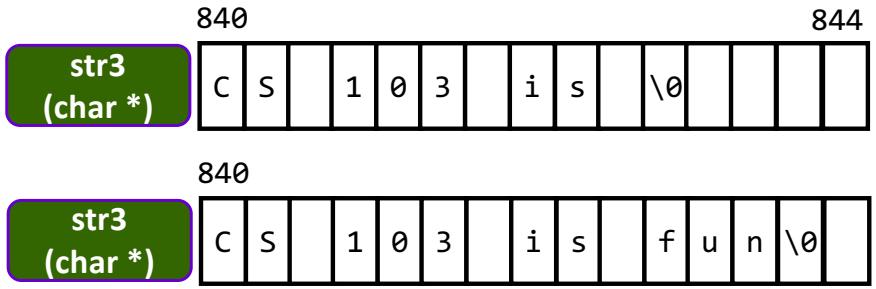
C (not C++) String Function/Library (#include <cstring>)

- A library of functions was provided to perform operations on these character arrays representing strings (`<cstring>` in C++, `<string.h>` in C)
  - `int strlen(char dest[]);`
    - Returns the length of the string (not counting the null character)
  - `int strcmp(char str1[], char str2[]);`
    - Return 0 if equal, >0 if str1 is alphanumerically larger than str2, <0 if str1 is less than str2
  - `char* strcpy(char dest[], char src[]);`
    - Copies the whole C-string from src to the dest array (overwriting what's in dest)
    - Ignore the return type for now (think of it as a void function)
  - `char* strcat(char dest[], char src[]);`
    - Concatenates src to the end of dest
    - Ignore the return type for now (think of it as a void function)

Use of the C-String Library

```
#include <iostream>
#include <cstring>
using namespace std;

int main()
{
  char str1[] = "CS103 is ";
  char str2[] = "fun";
  char str3[15];

  cin >> str3;  // user enters "cool"

  // What is this actually comparing?
  if(str3 == str1)
  if(0 == strcmp(str1,str3))
    { cout << "Match" << endl; }

  // Intuitively this makes sense but
  // will not compile in C/C++. Using your
  // knowledge of types and other info,
  // what is this actually attempting to do.
  str3 = str1;
  strcpy(str3, str1);

  str3 += str2;
  strcat(str3, str2);

  cout << str3 << endl;
  return 0;
}
```





Sample Implementations

- Exercises
  - strlen
  - strcpy

(Self study and ask questions)

SOLUTIONS AND MORE FUNCTION EXAMPLES

Pass by Value Solution

- Wait! But they have the same name, 'y'
  - What's in a name…Each function is a separate entity and so two 'y' variables exist (one in main and one in decrement it)
  - The only way to communicate back to main is via return
  - Try to change the code appropriately
- **Main Point:** Each function is a completely separate "sandbox" (i.e. is isolated from other functions and their data) and copies of data are passed and returned between them

```
void dec(int);
int main()
{
  int y = 3;
  dec(y);
  cout << y << endl;
  return 0;
}
void dec(int y)
{
   y--;
}
```

```
int dec(int);
int main()
{
  int y = 3;
  y = dec(y);
  cout << y << endl;
  return 0;
}
int dec(int y)
{
   y--;
   return y;
}
```

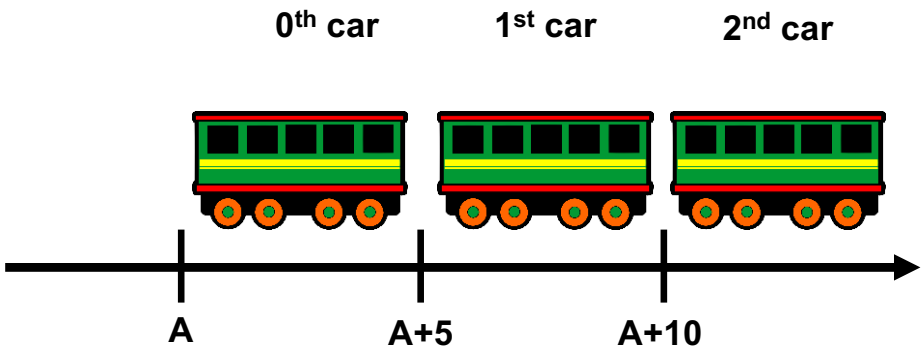
Exercise Solution

- Consider a train with many copies of the same car
  - The "0th" 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?

A + 5*i

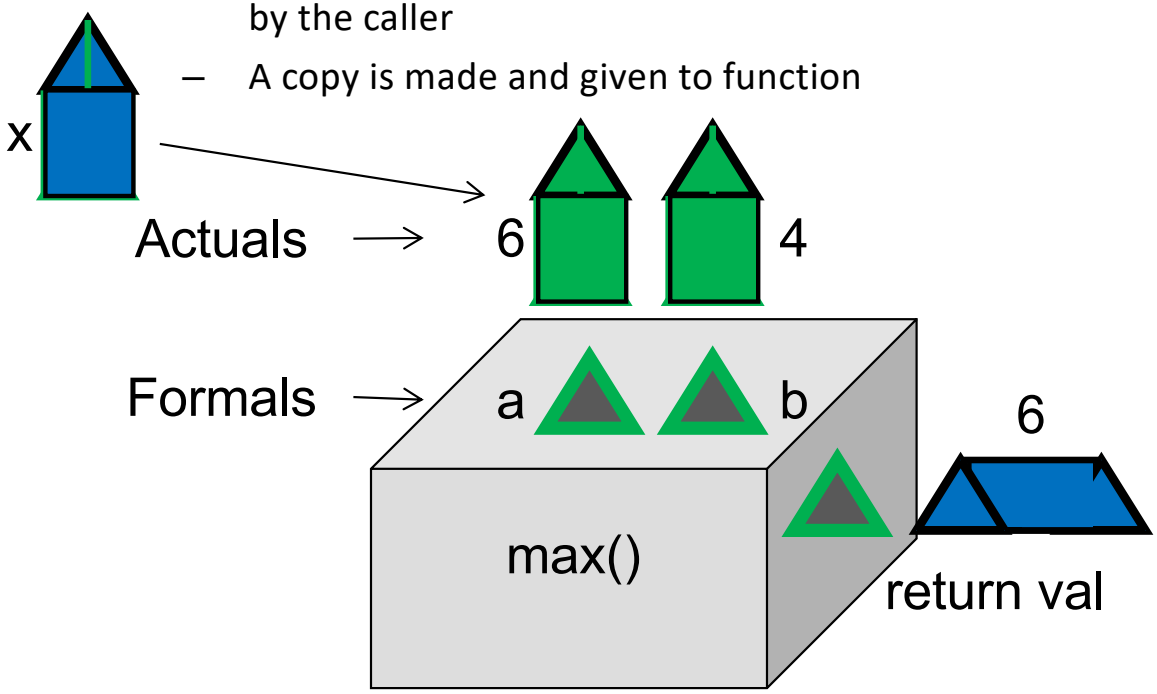
A + 4*i

A + 8*i



Parameter Passing (1)

- **Formal** parameters, a and b
  - Type of data the parameter expects
  - Names that will be used internal to the function to refer to the values passed (e.g. generic placeholders/titles used in contracts like "CEO" or "professor" that will be assigned or replaced real value)
- **Actual** parameters
  - Actual values ("Jeff Bezos", "Mark") input to the function by the caller
  - A copy is made and given to function



Each type is a "different" shape (int = triangle, double = square, char = circle). Only a value of that type can "fit" as a parameter.

```
#include <iostream>
using namespace std;

int max(int a, int b)
{
  if(a > b)
    return a;
  else
    return b;
}

int main()
{
   int x=6, z;
   z = max(x,4);
   cout << "AVG is " << z << endl;
   z = avg(x, 2);
   cout << "AVG is " << z << endl
   return 0;
}
```

Formals

Actuals

Actuals

Scope Example

- Globals live as long as the program is running
- Variables declared in a block { … } live as long as the block has not completed
  - { … } of a function
  - { … } of a loop, if statement, etc.
- When variables share the same name, the closest declaration will be used by default

```
#include <iostream>
using namespace std;

int x = 5;

int main()
{
  int a, x = 8, y = 3;
  cout << "x = " << x << endl;
  for(int i=0; i < 10; i++){
    int j = 1;
    j = 2*i + 1;
    a += j;
  }
  a = doit(y);
  cout << "a=" << a ;
  cout << "y=" << y << endl;
  cout << "glob. X" << ::x << endl;
}


int doit(int x)
{
   x--;
   return x;
}
```