University of Southern California

Viterbi School of Engineering

SW Design and Optimization

Pointers, Memory Allocation, …

References: Professor Mark Redekopp's slide units, online resources (papers, articles, etc.

Why Pointers

- Scenario: You write a paper and include a lot of large images. You can send the document as an attachment in the e-mail or upload it as a Google doc and simply e-mail the URL. What are the pros and cons or sending the URL?
- Pros
  - Less info to send (send link, not all data)
  - Reference to original
    (i.e., if original changes, you'll see it)
- Cons
  - Can treat the copy as a scratch copy and modify freely

Why Pointers (cont.)

- To change a variable (or variables) local to one function in some other function
  - Requires pass-by-reference (i.e. passing a pointer to the other function)
- When large data structures are being passed (i.e., arrays, class objects, structs, etc.)
  - So the computer doesn't waste time and memory making a copy
- When we need to ask for more memory as the program is running (i.e., dynamic memory allocation)
- To provide the ability to access specific location in the computer (i.e., hardware devices)
  - Useful for embedded systems programming

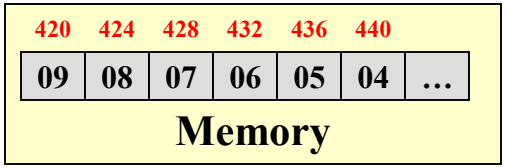
Pointer Analogy

- Imagine a set of 18 safe deposit or PO boxes each with a number
- There are 8 boxes with gold and the other 10 do not contain gold but hold a piece of paper with another box number (i.e. a pointer to another box)
- Value of box 9 “points-to” box 7
- Value of box 17 “points-to” box 3

0 8	1	2 15	3	4	5 3
6 11	7	8 4	9 7	10 3	11
12	13 1	14	15	16 5	17 3

Pointers are References

- Pointers are references to other things
  - Pointers are the address of some other variable in memory
  - "things" can be data, i.e., ints, chars, doubles) or other pointers
- The concept of a pointer is very common and used in many places in everyday life
  - Phone numbers, e-mail or mailing addresses are references or "pointers" to you or where you live
  - Excel workbook has cell names we can use to reference the data (=A1 means get data in A1)
  - URL's (www.usc.edu is a "pointer" to a physical HTML file) and can be used in any other page to "point to" USC's website



420 is a "pointer" to the integer 9
436 is a "pointer" to the integer 5

Prerequisites: Data Sizes, Computer Memory

POINTER BASICS

Review Questions

- The elements of an array are stored contiguously in memory

True or false!

- When an array is declared (i.e., int odt[10]) and its name is written by itself (e.g., x = odt;) in an expression, it evaluates to what?

odt[0] ?

C++ Pointer Operators

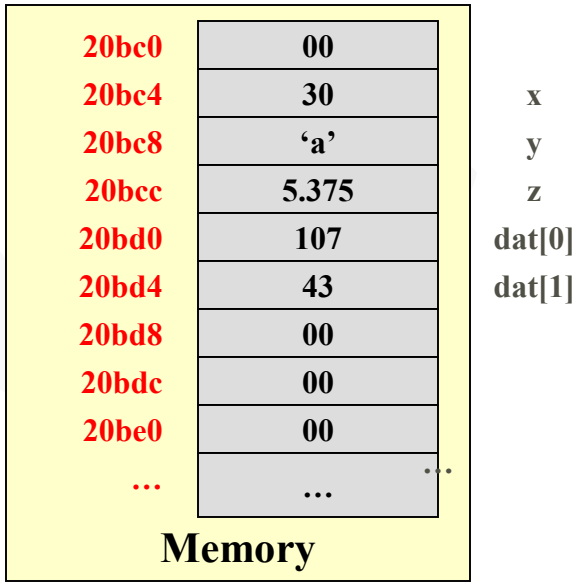
- Two operators used to manipulate pointers, i.e., addresses in C/C++: & and *
  - &*variable* evaluates to the "address-of" *variable*
    - *Essentially you get a pointer to something by writing &something*
  - ***pointer*** evaluates to the data pointed to by pointer (data at the address given by pointer)
  - & and * are essentially inverse operations
    - We say '&' returns a reference/address of some value while '*' dereferences the address and returns the value
    - &value => address
    - *address => value
    - *(&value) => value

Pointers

- ‘&’ operator yields address of a variable in C (Tip: Read ‘&foo’ as ‘address of foo’)

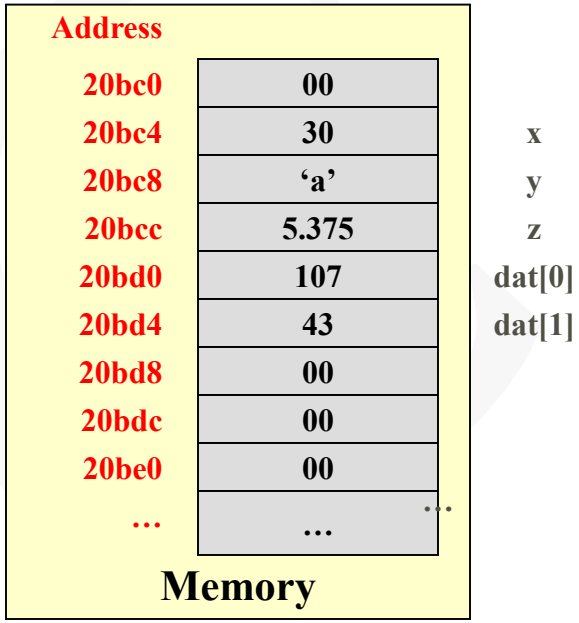
```
int x = 30;   char  y='a';
float z = 5.375;
int dat[2] = {107,43};
```

- `&x => ??,`
- `&y => ??,`
- `&z => ??,`
- `&dat[1] = ??;`
- `dat => ??`



Pointers (cont.)

- int x = 30; char y='a';
  float z = 5.375;
  int dat[2] = {107,43};
- `&x` => 0x20bc4,
- `&y` => 0x20bc8,
  `&z` => 0x20bcc,
- `&dat[1]` = 0x20bd4;
- `dat` => 0x20bd0



- Number of bits used for an address depends on OS, etc.
  - 32-bit OS => 32-bit addresses
  - 64-bit OS => 64-bit addresses

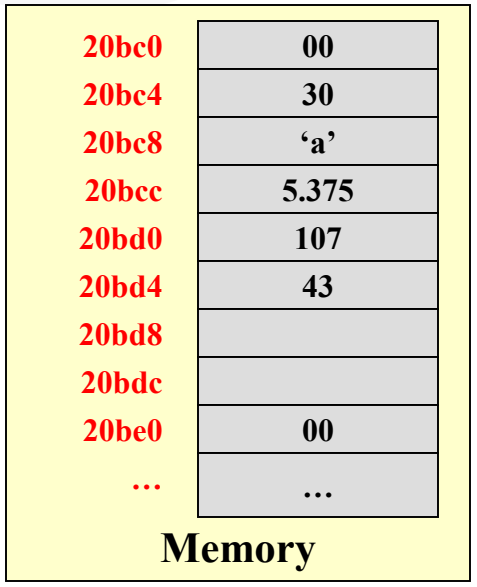
Pointers (cont.)

- Just as we declare variables to store ints and doubles, we can declare a pointer *variable* to store the "address-of" (or "pointer-to") another variable
  - Requires 4-bytes of storage in a 32-bit system or 8-bytes in a 64-bit systems
  - Use a '*' after the type to indicate this a pointer variable to that type of data
    - Why did people choose '*' to declare a pointer variable?
    - Because you'd have to put a '*' in front of the variable to get an actual data item (i.e. to get the int that an int pointer points to, put a '*' in front of the pointer variable.
- Declare variables:

```
int x = 30; char y='a';
float z = 5.375;
int dat[2] = {107,43};
```

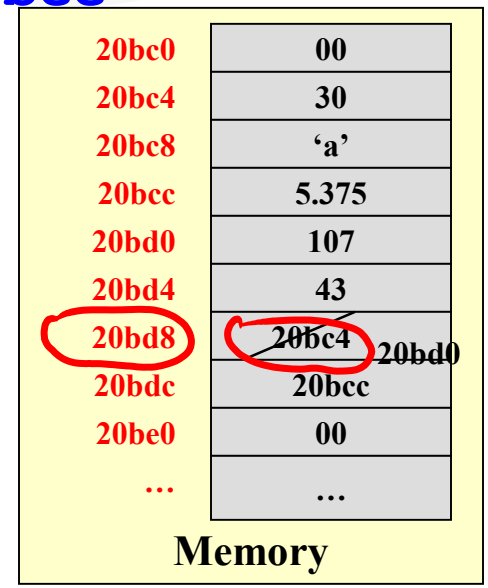
```
int *ptr1;
ptr1 = &x;          // ptr1 = 0x20bc4
ptr1 = &dat[0];     // Change ptr1 = 0x20bd0
//(i.e.you can change what a pointer points to)
```

```
float *ptr2 = &z; // ptr2 = 0x20bcc
```



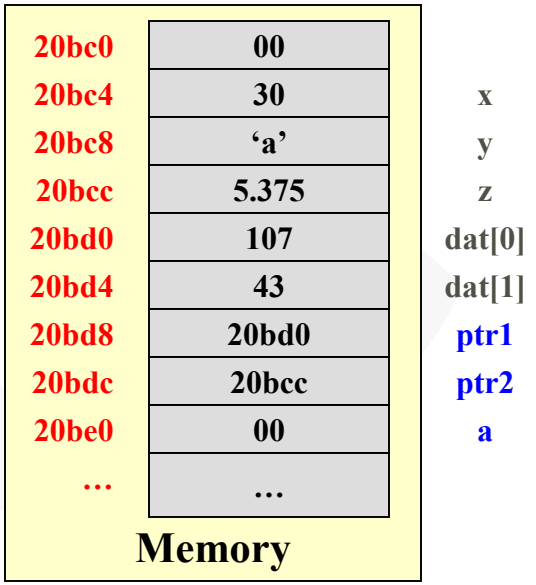
Pointers (cont.)

- **Declare variables:**
  - ```
    int x = 30; char y='a';
    float z = 5.375;
    int dat[2] = {107,43};
    ```
  - ```
    int *ptr1;
    ptr1 = &x;          // ptr1 = 0x20bc4
    ptr1 = &dat[0];     // Change ptr1 = 0x20bd0
    //i.e., you can change what a pointer points to
    ```
  - ```
    float *ptr2 = &z; // ptr2 = 0x20bcc
    ```


    ```

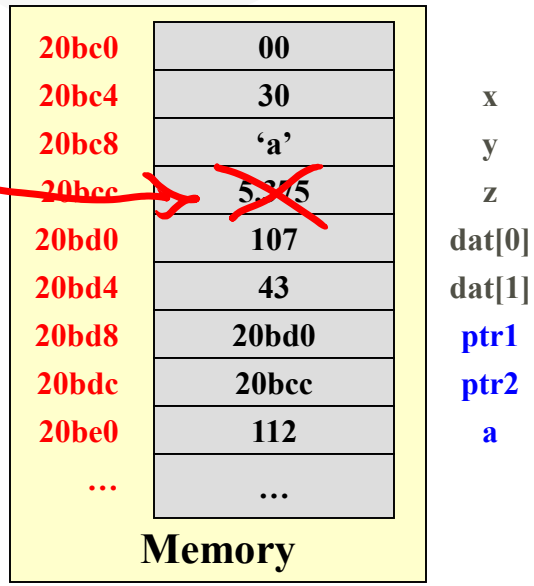
De-referencing / Indirection

- Once a pointer has been written with an address of some other object, we can use it to access that object (i.e. dereference the pointer) using the '*' operator
- Read '*foo' as...
  - 'value pointed to by foo'
  - 'value at the address given by foo'
    (not 'value of foo' or 'value of address of foo')
- Using URL analogy, using the * operator on a pointer is like "clicking on a URL" (follow the link)
- Examples:
  - ptr1 = dat;
    int a = *ptr1 + 5;
  - (*ptr1)++; // *ptr = *ptr + 1;
  - *ptr2 = *ptr1 - *ptr2;



De-referencing / Indirection (cont.)

- Examples:
  - int a = 5 + *ptr1; // a = 112 after exec.
  - (*ptr1)++; // dat[0] = 108
  - *ptr2 = *ptr1 - *ptr2; // z = 108 – 5.375 = 102.625
- '*' in a type declaration = declare/allocate a pointer
- '*' in an expression/assignment = dereference



Cutting through the Syntax

- '*' in a type declaration = declare/allocate a pointer
- '*' in an expression/assignment = dereference

	Declaring a pointer	De-referencing a pointer
char *p	Yes	
*p + 1		Yes
int *ptr	Yes	
*ptr = 5		Yes
*ptr++		Yes
char *p1[10];	Yes	

Helpful tip to understand syntax: We declare an int pointer as:

- **int *p because when we dereference it as *p we get an int**
- **char *x is a declaration of a pointer and thus *x in code yields a char**

Exercise: ch13p6

Prerequisites: Pointer Basics, Data Sizes

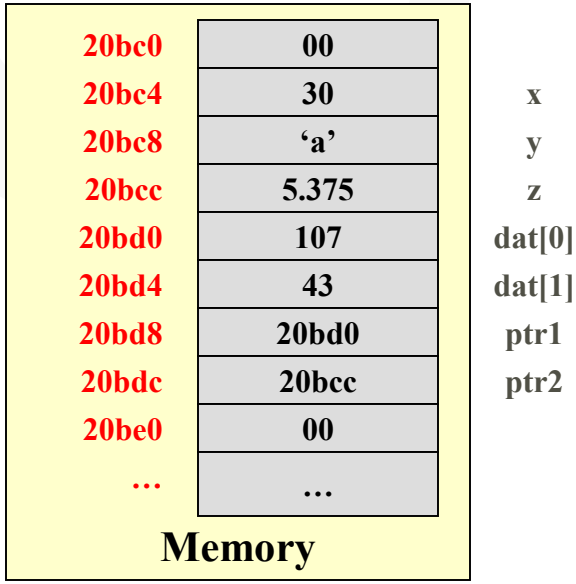
POINTER ARITHMETIC

Review Questions

- The size of an 'int' is how many bytes?
  - 4
- The size of a 'double' is how many bytes?
  - 8
- What does the name of an array evaluate to?
  - It's start address...
  - Given the declaration int dat[10], dat is an int*
  - Given the declaration char str[6], str is a char*
- In an array of integers, if dat[0] lived at address 0x200, dat[?] would live at...?
  - 0x204

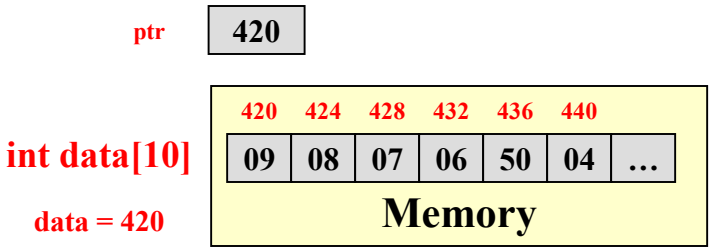
Pointer Arithmetic

- Pointers are variables storing addresses and addresses are just numbers
- We can perform addition or subtraction on those pointer variables (i.e. addresses) just like any other variable
- The number added/subtracted is implicitly multiplied by the size of the object so the pointer will point to a valid data item
  - int *ptr = dat; ptr = ptr + 1;
  - // address in ptr was incremented by 4
- Examples:
  - int* ptr1 = dat;
  - x = x +*ptr1; // x = 137
  - ptr1 = ptr1 + 1; // ptr1 now points at dat[1]
  - x = x + *ptr1++; // x = dat[1] = 137+43 then
    // inc. ptr1 to 0x20bd8
  - ptr1 = ptr1-2; // ptr1 now points back at dat[0]



Pointer Arithmetic and Array Indexing

- Array indexing and pointer arithmetic are very much related
- Array syntax: data[i]
  - Says get the i-th value from the start of the data array
- Pointer syntax: *(data + i)
  - Says the same thing as data[i]
- We can use pointers and array names interchangeably:
  - int data[10]; // data = 420;
  - *(data + 4) = 50; // data[4] = 50;
  - int* ptr = data; // ptr now points at 420 too
  - ptr[1] = ptr[2] + ptr[3]; // same as data[1] = data[2] + data[3]



Arrays & Pointers

- Have a unique relationship
- Array name evaluates to start address of array
  - Thus, the name of an integer array has type: int*
  - The name of character array / text string has type: char*
- Array indexing is same as pointer arithmetic

```
int main(int argc, char *argv[])
{
  int data[10] = {9,8,7,6,5,4,3,2,1,0};

  int* ptr, *another;  // * needed for each
                       //  ptr var. you
                       //  declare

  ptr = data;      // ptr = start address
                   //       of data

  another = data; // another = start addr.

  for(int i=0; i < 10; i++){
    data[i] = 99;
    ptr[i] = 99;  // same as line above
    *another = 99; // same as line above
    another++;

  }

  int x = data[5];
  x = *(ptr+5);  // same as line above
  return 0;
}
```

Prerequisites: Pointer Basics

PASS BY REFERENCE

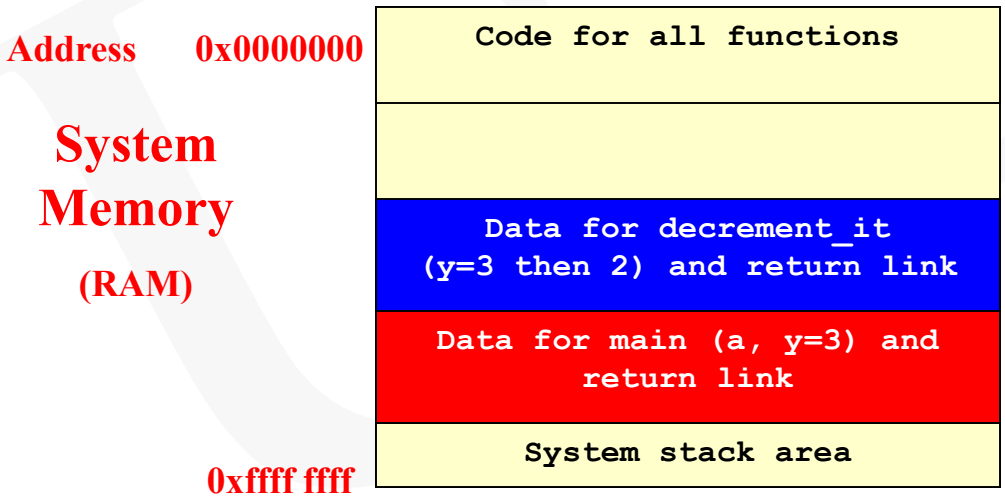
Pass by Value

- Notice that actual arguments are different memory locations/variables than the formal arguments
- When arguments are passed a copy of the actual argument value (e.g., 3) is placed in the formal parameter (x)
- The value of y cannot be changed by any other function (remember it is local)

```
void decrement_it(int);

int main()
{
  int a, y = 3;
  decrement_it(y);
  cout << "y = " << y << endl;
}

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

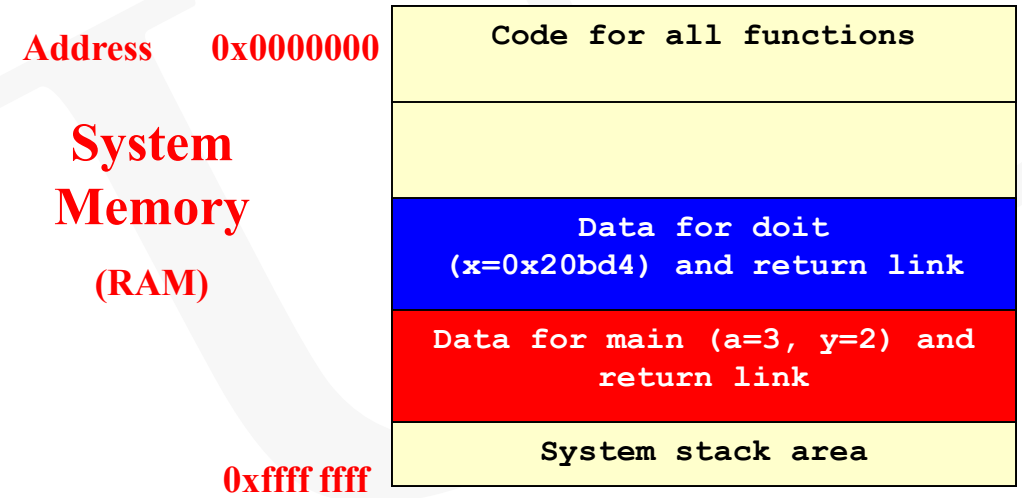


Pass by Reference

- Pointer value (i.e. the address) is still passed-by-value (i.e. a copy is made)
- However, the value of the pointer is a reference to y (i.e. y's address) and it is really the value of y that doit() operates on
- Thus we say we are passing-by-reference
- The value of y is CHANGED by doit() and that change is visible when we return

```
int main()
{
  int a, y = 3;
  // assume y @ 0x20bd4
  // assume ptr
  a = y;
  decrement_it(&y);
  cout << "a=" << a;
  cout << "y=" << y << endl;
  return 0;
}


// Remember * in a type/
// declaration means "pointer"
// variable
void decrement_it(int* x)
{
   *x = *x - 1;
}
```



Resulting Output:

a=3, y=2

Swap Two Variables

- Classic example of issues with local variables:
  - Write a function to swap two variables
- Pass-by-value doesn't work
  - Copy is made of x,y from main and passed to x,y of swapit...Swap is performed on the copies
- Pass-by-reference (pointers) does work
  - Addresses of the actual x,y variables in main are passed
  - Use those address to change those physical memory locations

```
int main()
{
  int x=5,y=7;
  swapit(x,y);
  cout << "x=" << x << " y=";
  cout << y << endl;
}

void swapit(int x, int y)
{   int temp;
    temp = x;
    x = y;
    y = temp;
}
```

program output: x=5,y=7

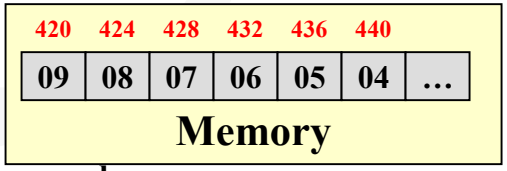
```
int main()
{ int x=5,y=7;
  swapit(&x,&y);
  cout << "x=" << x << "y=";
  cout << y << endl;
}

void swapit(int *x, int *y)
{   int temp;
    temp = *x;
    *x = *y;
    *y = temp;
}
```

program output: x=7,y=5

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;
}

void add_1_to_array_of_10(int my_array[])
{
  int i=0;
  for(i=0; i < 10; i++){
    my_array[i]++;
  }
}
void add_1_to_array(int *my_array, int size)
{
  int i=0;
  for(i=0; i < size; i++){
    my_array[i]++;
  }
}
```

420 420 420

Argument Passing Example

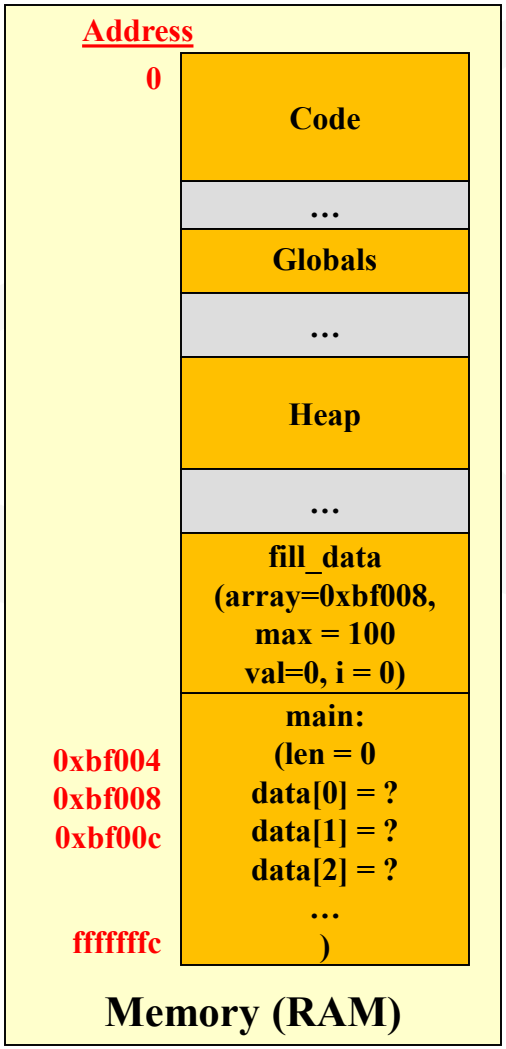
```
#include <iostream>
using namespace std;

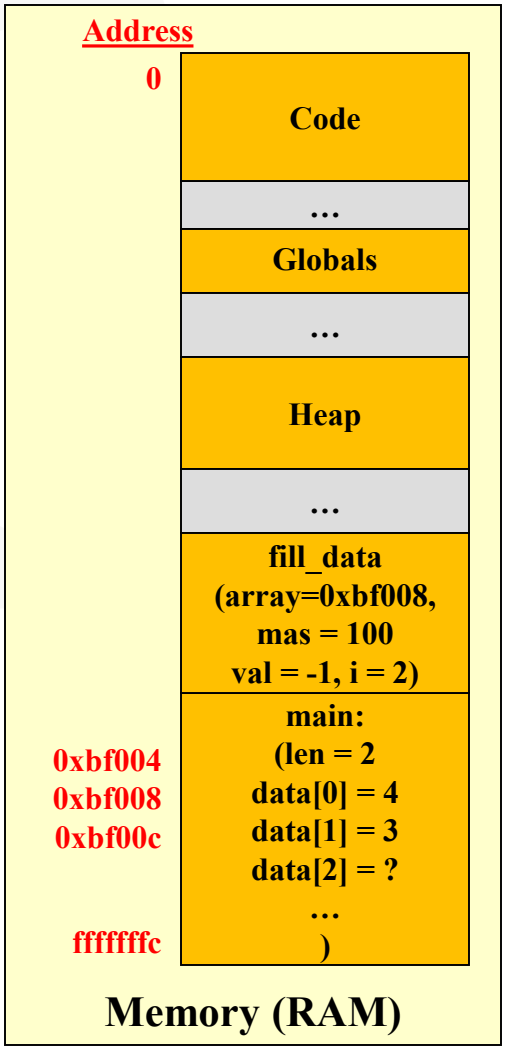
int main()
{
  int len=0;
  int data[100];

  len = fill_data(data, 100);

  for(int i=0; i < len; i++)
    cout << data[i] << " ";
  cout << endl;
  return 0;
}

// fills in integer array w/ int's
// from user until -1 is entered
int fill_data(int *array, int max)
{
   int val = 0;
   int i = 0;
   while(i < max){
     cin >> val;
     if (val != -1)
       array[i++] = val;
     else
       break;
   }
   return i;
}
```





Exercises

- Swap
- Roll2

Prerequisites: Pointer Basics

POINTERS TO POINTERS

Pointers to Pointers Analogy

- We can actually have multiple levels of indirection (de-referencing)
- Using C/C++ pointer terminology:
  - *9 = gold in box 7 (9 => 7)
  - **16 = gold in box 3 (16 => 5 => 3)
  - ***0 = gold in box 3 (0 => 8 => 5 =>3)

0 8	1	2 15	3	4	5 3
6 11	7	8 **5**	9 7	10 3	11
12	13 1	14	15	16 5	17 3

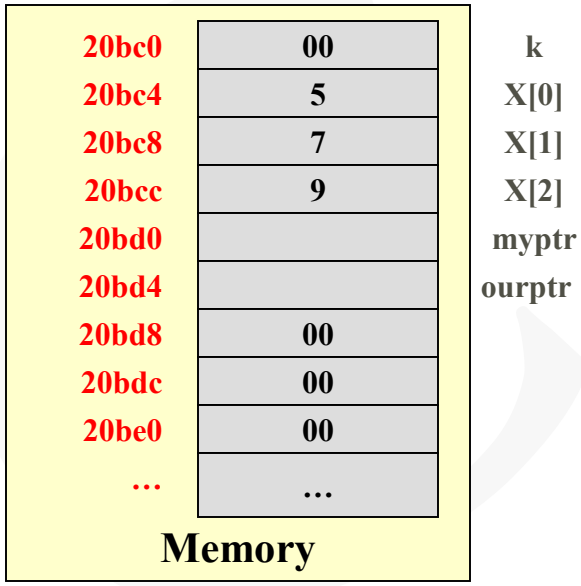
Pointer Analogy

- What if now rather than holding gold, those boxes simply held other numbers
- How would you differentiate whether the number in the box was a “pointer” to another box or a simple data value?
  - You can’t really. Context is needed
- This is why we have to declare something as a pointer and give a type as well:
  - int *p; // pointer to an integer one hop (one level of indirection) away
  - double **q; // pointer to a double two hops (two levels of indirection) away

0 8	1 9	2 15	3 12	4 2	5 3
6 11	7 9	8 4	9 7	10 3	11
12 11	13 1	14 18	15 10	16 5	17 3

Pointers to Pointers to...

- Pointers can point to other pointers
  - Essentially a chain of “links”
- Example
  - int k, x[3] = {5, 7, 9};
  - int *myptr, **ourptr;
  - myptr = x;
  - ourptr = &myptr;
  - k = *myptr;
  - k = (**ourptr) + 1;
  - k = *(*ourptr + 1);

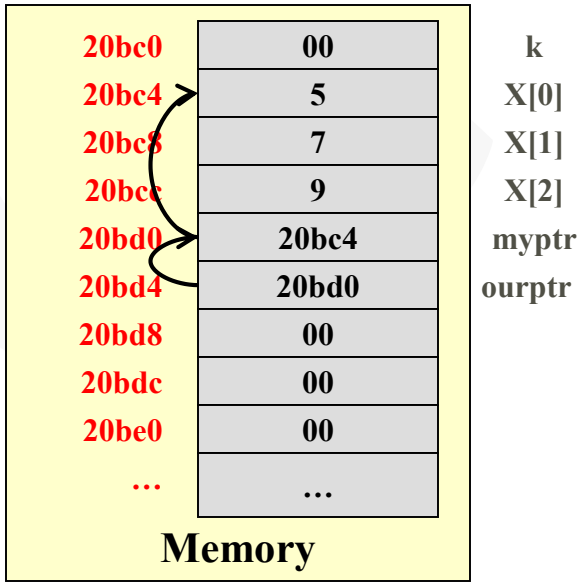


To figure out the type of data a pointer expression will yield…Take the type of pointer in the declaration and let each * in the expression 'cancel' one of the *'s in the declaration

Type Decl.	Expr	Yields
myptr = int*	*myptr	int
ourptr = int**	**ourptr	int
	*ourptr	int*

Pointers to Pointers to... (cont.)

- Pointers can point to other pointers
  - Essentially a chain of "links"
- Example
  - int k, x[3] = {5, 7, 9};
  - int *myptr, **ourptr;
  - myptr = x;
  - ourptr = &myptr;
  - k = *myptr; // k = 5
  - k = (**ourptr) + 1; // k = 6
  - k = *(*ourptr + 1); // k = 7



why!

Check Yourself

- Consider these declarations:
  - int k, x[3] = {5, 7, 9};
  - int *myptr = x;
  - int **ourptr = &myptr;
- Indicate the formal type that each expression evaluates to, i.e., int, int *, int **

Expression	Type
x[0]	
x	
myptr	
*myptr	
*ourptr	
myptr + 1	
ourptr	

Check Yourself (cont.)

Expression	Type
x[0]	Int
x	Int *
myptr	Int *
*myptr	Int
*ourptr	Int *
myptr + 1	Int *
ourptr	Int **

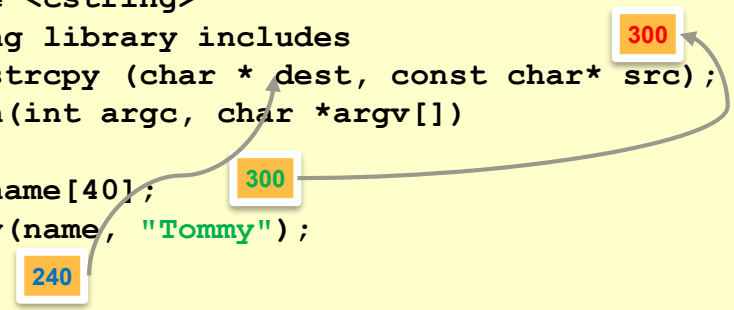
ARRAYS OF POINTERS AND C-STRINGS

C-String Constants

- C-String constants are the things we type in "..." and are stored somewhere in memory (chosen by the compiler)
- When you pass a C-string constant to a function it passes the start address and it's type is known as a const char *
  - char* because you are passing the address
  - const because you cannot/should not change this array's contents

```
int main(int argc, char *argv[])
{
  // These are examples of C-String constants
  cout << "Hello" << endl;
  cout << "Bye!" << endl;
  ...
}
```


```
#include <cstring>
//cstring library includes
//void strcpy (char * dest, const char* src);
int main(int argc, char *argv[])
{
  char name[40];
  strcpy(name, "Tommy");
}
```



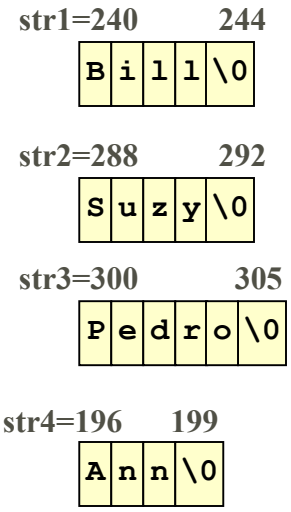
Arrays of pointers

- We often want to have several arrays to store data
  - Store several text strings
- Those arrays may be related, i.e., all names of students in a class

```
int main(int argc, char *argv[])
{
  int i;
  char str1[] = "Bill";
  char str2[] = "Suzy";
  char str3[] = "Pedro";
  char str4[] = "Ann";

  // I would like to print out each name
  cout << str1 << endl;
  cout << str2 << endl;
  ...
}
```

Painful



Arrays of pointers (cont.)

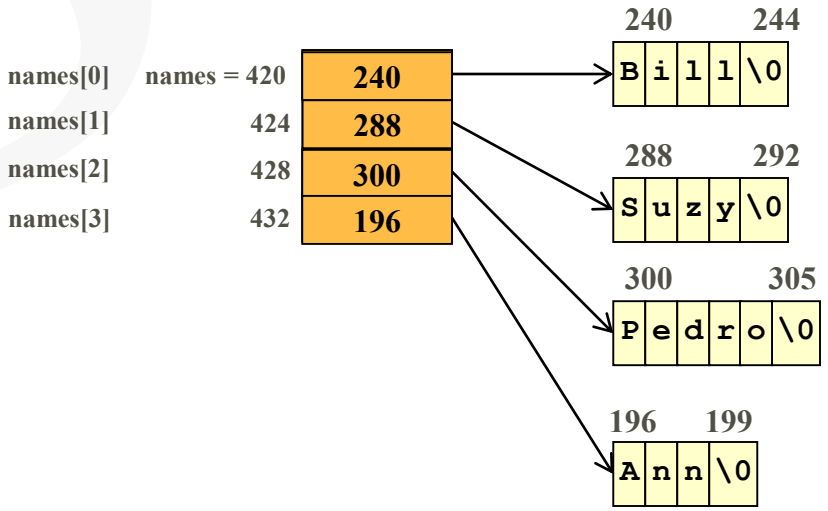
- What type is 'names'?
  - The address of the 0th char* in the array
  - The address of a char* is really just a char**

```
int main(int argc, char *argv[])
{
  int i;
  char str1[] = "Bill";
  char str2[] = "Suzy";
  char str3[] = "Pedro";
  char str4[] = "Ann";
  char *names[4];

  names[0] = str1; ...; names[3] = str4;

  for(i=0; i < 4; i++){
    cout << names[i] << endl;
  }
  ...
}
```

Still painful



Arrays of pointers (cont.)

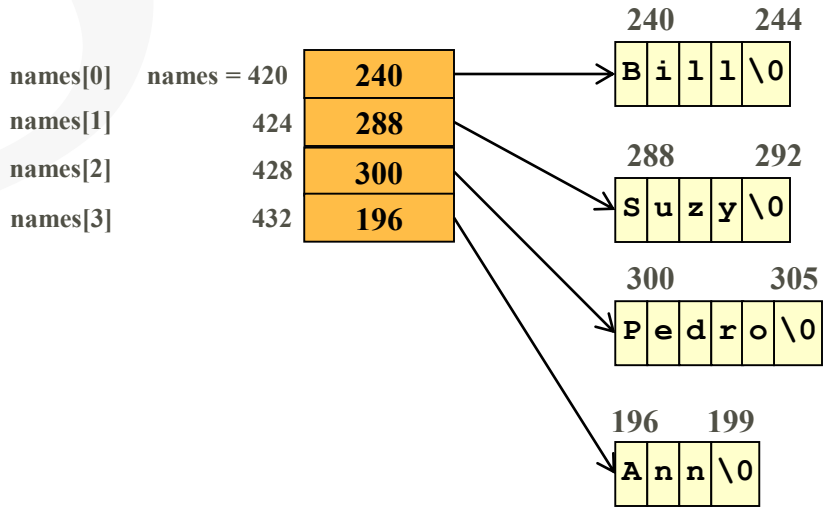
- We can have arrays of pointers just like we have arrays of other data types
- Usually each value of the array is a pointer to a collection of "related" data
  - Could be to another array

```
char *names[4] ={"Bill",
                 "Suzy",
                 "Pedro",
                 "Ann"};

int main(int argc, char *argv[])
{
  int i;

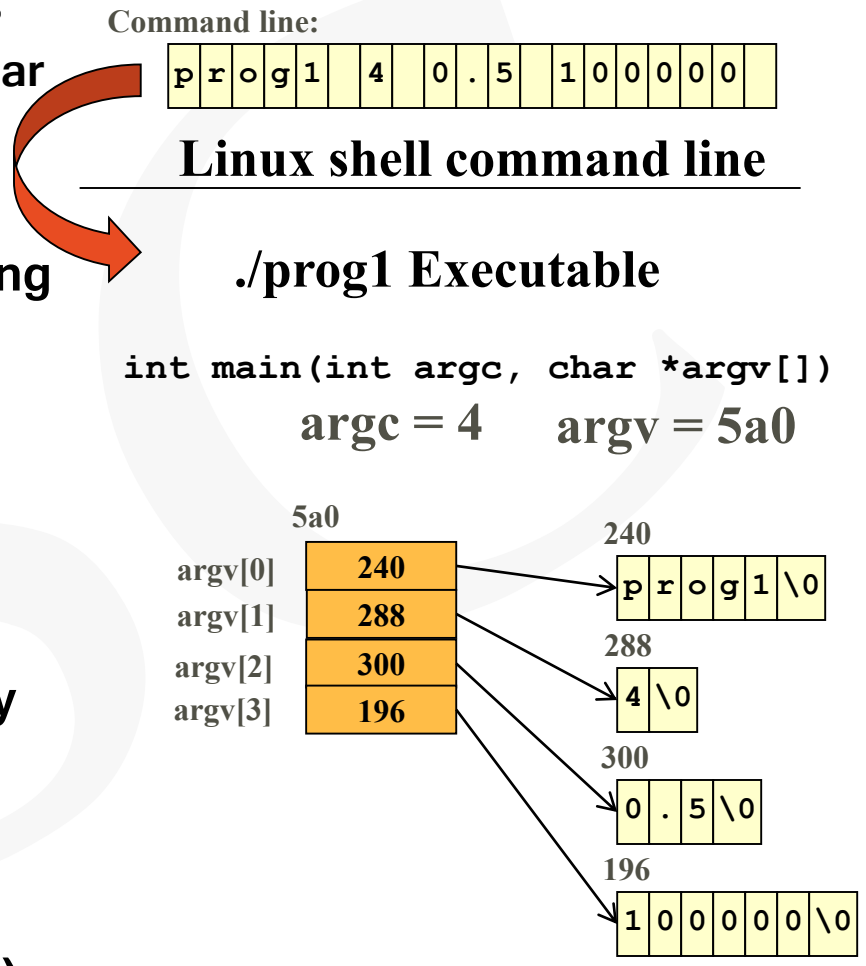
  for(i=0; i < 4; i++){
    cout << names[i] << endl;
  }
  return 0;
}
```

Painless?!?



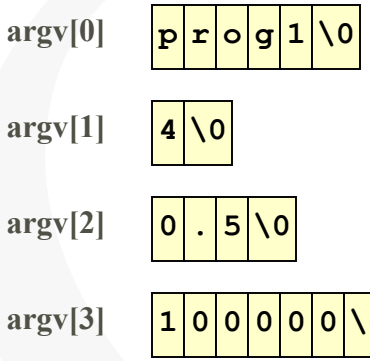
Command Line Arguments

- Now we can understand the arguments passed to the main function (int argc, char *argv[])
- At the command prompt we can give inputs to our program rather than making querying the user interactively:
  - $ ./prog1 4 0.5 100000
  - $ cp broke.c broke2.c
- Command line string is broken at whitespaces and copied into individual strings and then packaged into an array (argv)
  - Each entry is a pointer to a string (char *)
- Argc indicates how long that arrays is (argv[0] is always the executable name)



Command Line Arguments (cont.)

- Recommended usage:
  - Upon startup check argc to make sure the user has input the desired number of args (remember the executable counts as one of the args.)
- Problem:
  - Each argument is a text string...for numbers we want its numeric representation not its ASCII representation
  - cstdlib defines:
    atoi() [ASCII to Integer] and
    atof() [ASCII to float/double]
  - Each of these functions expects a
    pointer to the string to convert




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

// char **argv is the same as char *argv[]
int main(int argc, char **argv)
{
  int init, num_sims;
  double p;
  if(argc < 4){
    cout << "usage: prog1 init p sims" << endl;
    return 1;
  }

  init = atoi(argv[1]);
  p = atof(argv[2]);
  num_sims = atoi(argv[3]);

  ...
```

Review: String Function/Library (#include <cstring>)

- int strlen(char *dest)
- int strcmp(char *str1, char *str2);
  - Return 0 if equal, >0 if first non-equal char in str1 is alphanumerically larger, <0 otherwise
- char *strcpy(char *dest, char *src);
  - strncpy(char *dest, char *src, int n);
  - Maximum of n characters copied
- char *strcat(char *dest, char *src);
  - strncat(char *dest, char *src, int n);
  - Maximum of n characters concatenated plus a NULL
- char *strchr(char *str, char c);
  - Finds first occurrence of character ‘c’ in str returning a pointer to that character or NULL if the character is not found

Exercises

- cmdargs_sum
- cmdargs_smartsum
- cmdargs_smartsum_str
- toi

Recap: Why Use Pointers

- To change a variable (or variables) local to one function in some other function
  - Requires pass-by-reference, i.e., passing a pointer to the other function)
- When large data structures are being passed, i.e.. arrays, class objects, structs, etc.
  - So the computer doesn't waste time and memory making a copy
- To provide the ability to access specific location in the computer, i.e., hardware devices
  - Useful for embedded systems programming
- When we need a variable address, i.e., we don't or could not know the address of some desired memory location BEFORE runtime

Pointer Basics

DYNAMIC MEMORY ALLOCATION

Dynamic Memory Allocation

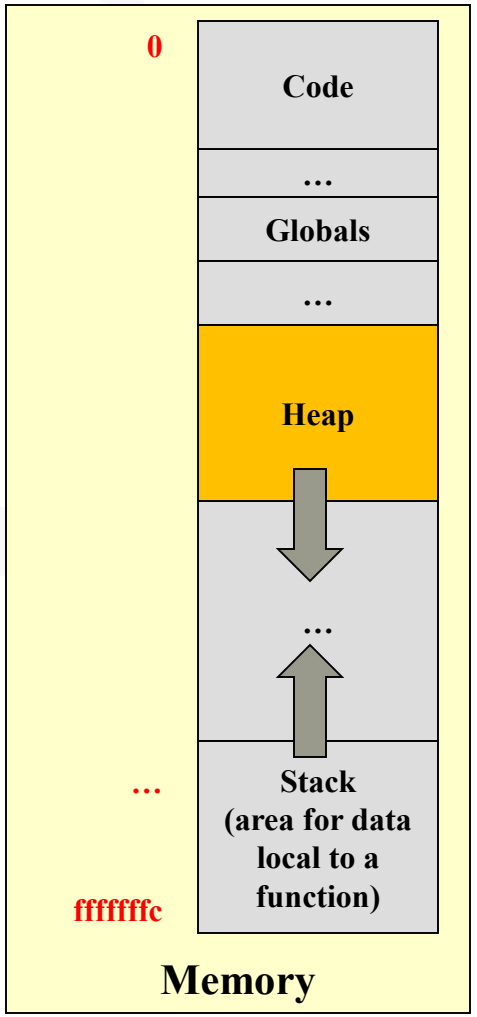
- Question: We want an array for student scores but I don't know how many students we have until the user tells me
- What size should I use to declare my array?
  - int scores[??]
- Doing the following is not supported by all C/C++ compilers:

```
int num;
cin >> num;
int scores[num];   // Some compilers require the array size
                   // to be statically known
```

- Also, recall local variables die when a function returns
- We can allocate memory *dynamically*, i.e., at run-time
  - If we don't know how much we'll need until run-time
  - If we want memory to live beyond the end of a functions, i.e., we want to control when memory is allocated and deallocated

Dynamic Memory & the Heap

- Code usually sits at low addresses
- Global variables somewhere after code
- System stack (memory for each function instance that is alive)
  - Local variables
  - Return link (where to return)
  - etc.
- 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
- Heap grows downward, stack grows upward...
  - In rare cases of large memory usage, they could collide and cause your program to fail or generate an exception/error



C Dynamic Memory Allocation

- malloc(*int num_bytes*) function in stdlib.h
  - Allocates the number of bytes requested and returns a pointer to the block of memory
- free*(void * ptr)* function
  - Given the pointer to the (starting location of the) block of memory, free returns it to the system for re-use by subsequent malloc calls

C++ new & delete operators

- new allocates memory from heap
  - replaces “malloc”
  - followed with the type of the variable you want or an array type declaration
    - `double *dptr = new double;`
    - `int *myarray = new int[100];`
  - can obviously use a variable to indicate array size
  - returns a pointer of the appropriate type
    - if you ask for a new int, you get an int * in return
    - if you ask for an new array (new int[10]), you still get an int * in return]
- delete returns memory to heap
  - Replaces “free”
  - followed by the pointer to the data you want to de-allocate
    - `delete dptr;`
  - use `delete []` for arrays
    - `delete [] myarray;`

Dynamic Memory Analogy

- Dynamic Memory is “ON-Demand Memory”
- Analogy: Public storage rentals
  - Need extra space, just ask for some storage and indicate how much you need (‘new’ statement with space allocated from the heap)
  - You get back the “address”/storage room number (‘new’ returns a pointer to the allocated storage)
  - Use the storage/memory until you are done with it
  - Need to return it when done or else no one else will ever be able to re-use it

Dynamic Memory Allocation

```
int main(int argc, char *argv[])
{
  int num;

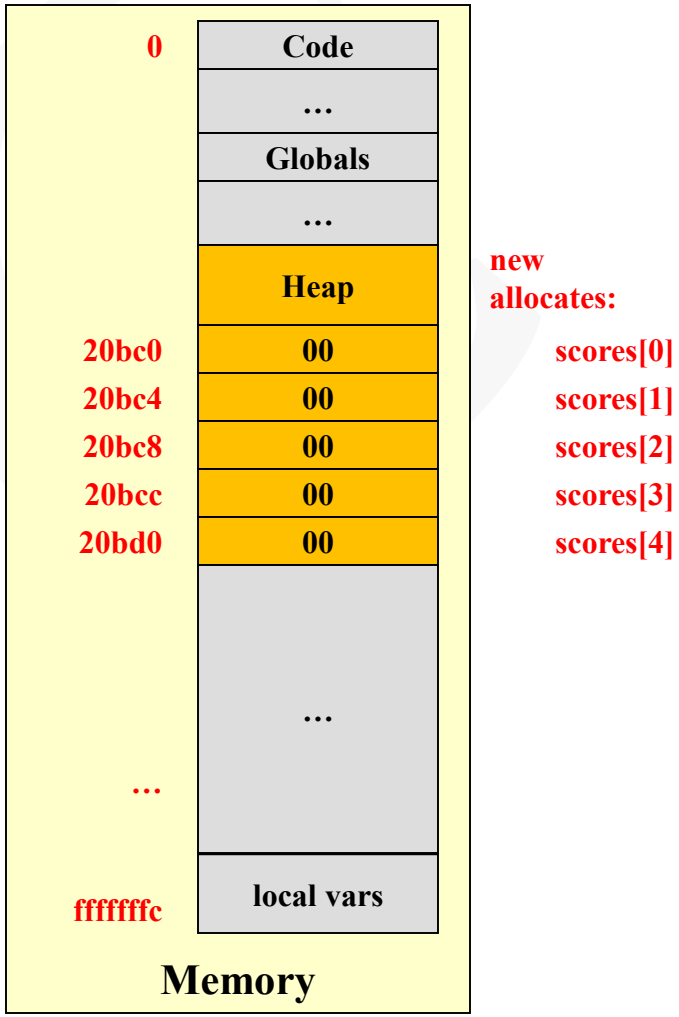
  cout << "How many students?" << endl;
  cin >> num;

  int *scores = new int[num];
  // can now access scores[0] .. scores[num-1];
  return 0;
}
```

```
int main(int argc, char *argv[])
{
  int num;

  cout << "How many students?" << endl;
  cin >> num;

  int *scores = new int[num];
  // can now access scores[0] .. scores[num-1];
  delete [] scores
  return 0;
}
```



Fill in the Blanks

- Try these and find the right syntax:

_____ data = new int;

_____ data = new char;

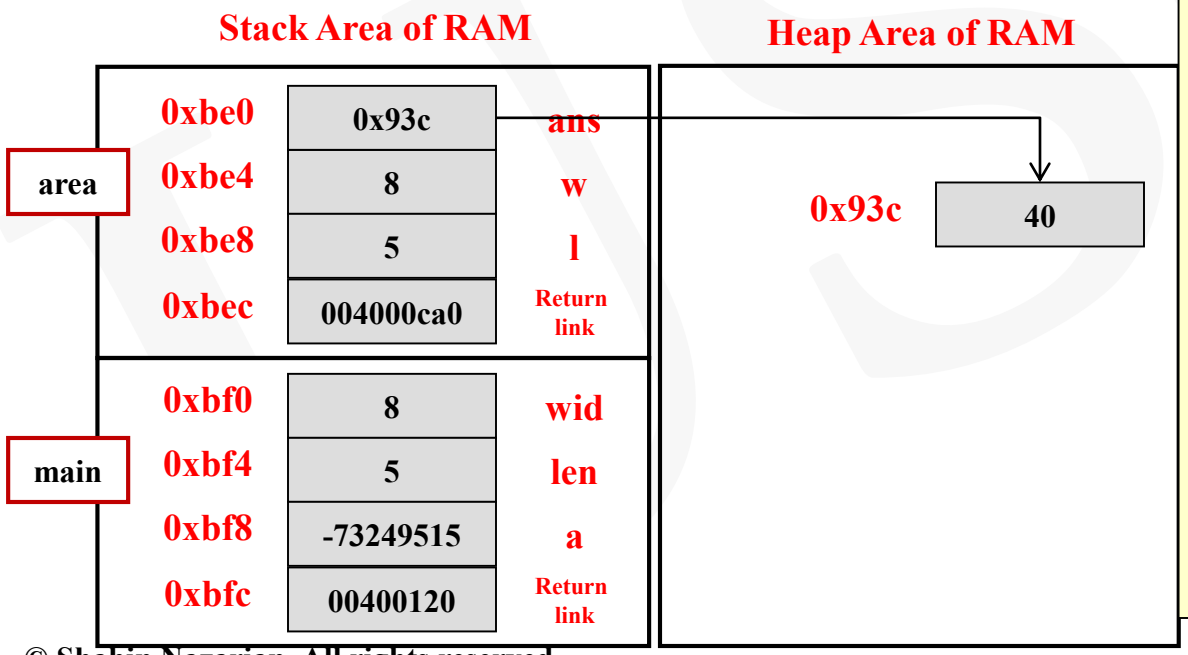
_____ data = new char[100];

_____ data = new char*[20];

_____ data = new string;

Dynamic Allocation

- Dynamic Allocation
  - Lives on the heap
    - Doesn't have a name, only pointer/address to it
  - Lives until you 'delete' it
    - Doesn't die at end of function (though pointer to it may)
- Let's draw these as boxes in the heap area

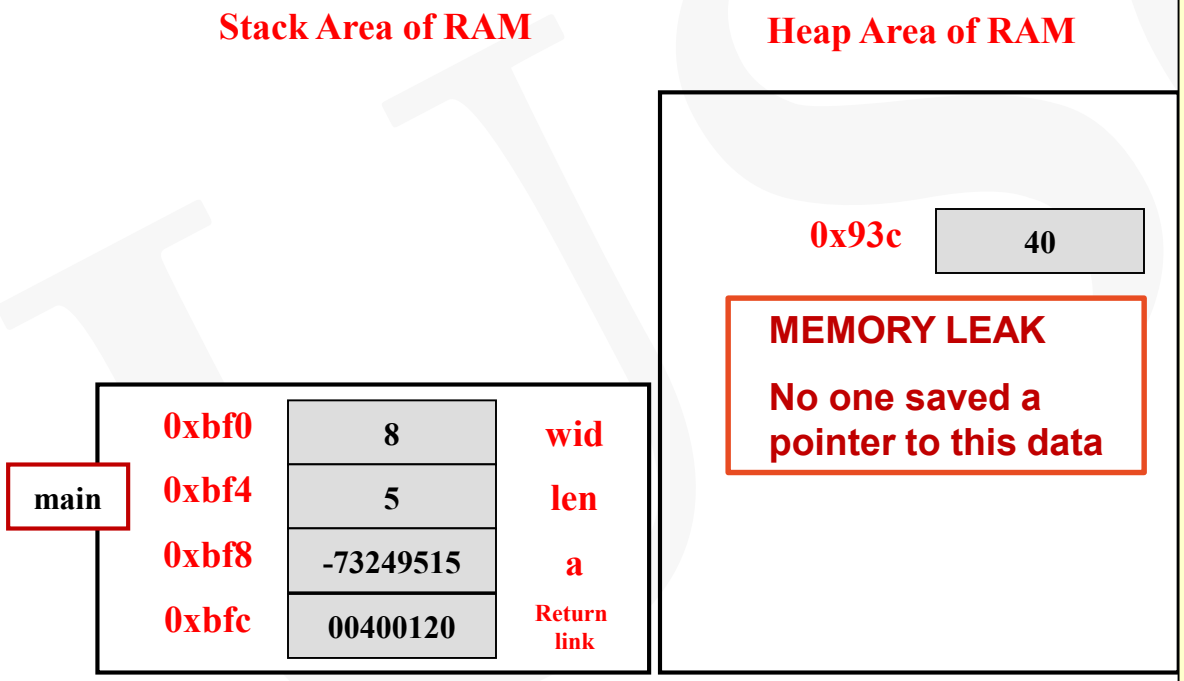



```
// Computes rectangle area,
//  prints it, & returns it
int* area(int, int);
void print(int);

int main()
{
  int wid = 8, len = 5, a;
  area(wid,len);
}


int* area(int w, int l)
{
  int* ans = new int;
  *ans = w * l;
  return ans;
}
```

Dynamic Allocation (cont.)

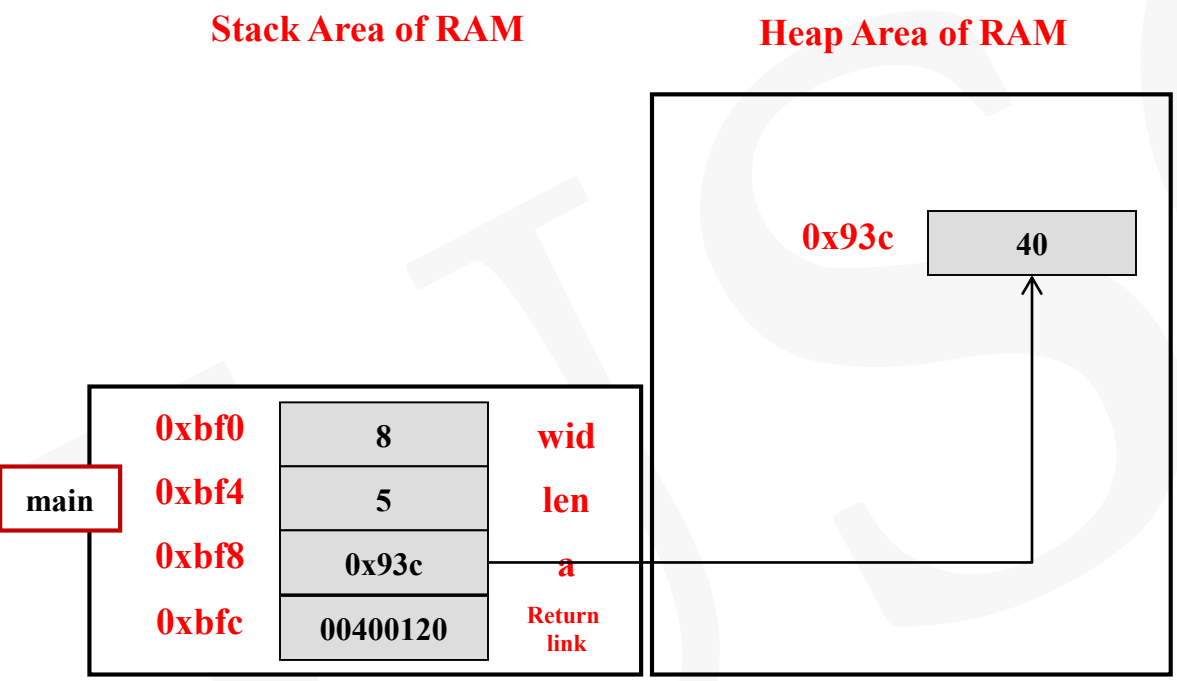



```
// Computes rectangle area,
//  prints it, & returns it
int* area(int, int);
void print(int);

int main()
{
  int wid = 8, len = 5, a;
  area(wid,len);
}


int* area(int w, int l)
{
  int* ans = new int;
  *ans = w * l;
  return ans;
}
```

Dynamic Allocation (cont.)




```
// Computes rectangle area,
//  prints it, & returns it
int* area(int, int);
void print(int);
int main()
{
  int wid = 8, len = 5, *a;
  a = area(wid,len);
  cout << *a << endl;
  delete a;
}

int* area(int w, int l)
{
  int* ans = new int;
  *ans = w * l;
  return ans;
}
```

SHALLOW VS. DEEP COPY

Dealing with Text Strings

- What is the best way to store text strings for data that we will not know until run time and that could be short or long?
- Statically:
  - Bad! Either wastes space or some user will enter a string just a little too long

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

int main()
{
  // store 10 user names of up to
  // 40 chars
  char names[10][40];

  for(int i=0; i < 10; i++){
    cin >> names[i];
  }
}
```

names[0]	"Tim"
names[1]	"Christopher"
…	

Jagged 2D-Arrays

DTRUMP
FBI
NUNES
RUSSIAPUTI

- What we want is just enough storage for each text string
- This is known as a jagged 2D-Array since each array is a different length
- To achieve this we will need an array of pointers
  - Each pointer will point to an array of different length

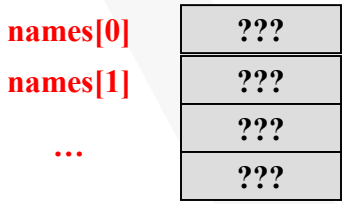

```
#include <iostream>
using namespace std;

int main()
{
  // store 10 user names of up to
  // 40 chars
  char *names[10];

  for(int i=0; i < 10; i++){
    cin >> names[i];
  }
}
```

More Dealing with Text Strings

- Will this code work to store 10 names?
  - Exercise: deepnames
- No!! You must allocate storage, i.e., an actual array, before you have pointers pointing to things...
  - Just because I made up the URL: http://docs.google.com/uR45y781 doesn't mean there's a document there...




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


int main()
{
  // store 10 user names
  //   names type is still char **
  char* names[10];

  for(int i=0; i < 10; i++){
    cin >> names[i];
  }

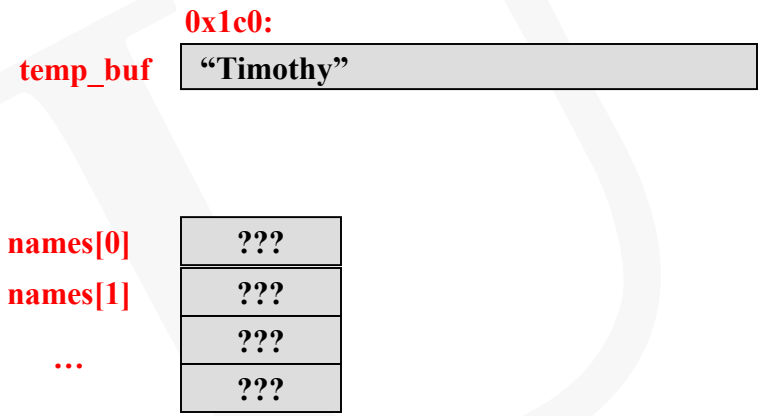
  // Do stuff with names


  for(int i=0; i < 10; i++){
    delete [] names[i];
  }

  return 0;
}
```

More Dealing with Text Strings (cont.)

- Will this code work to store 10 names?




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


int main()
{
  // store 10 user names
  //   names type is still char **
  char* names[10];


  char temp_buf[40];
  for(int i=0; i < 10; i++){
    cin >> temp_buf;
    names[i] = temp_buf;

  }

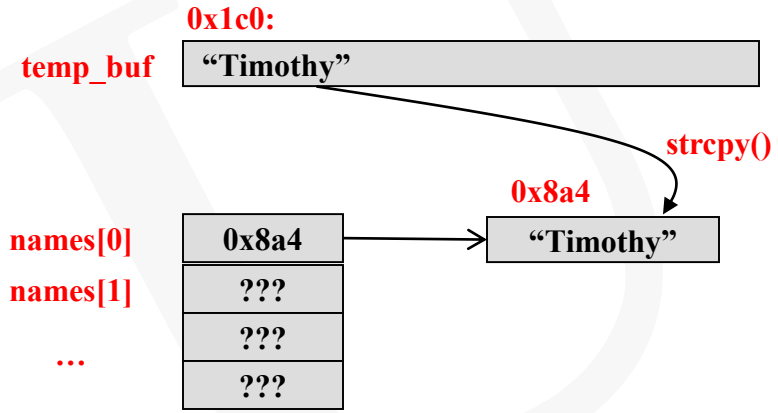
  // Do stuff with names


  for(int i=0; i < 10; i++){
    delete [] names[i];
  }

  return 0;
}
```

More Dealing with Text Strings (cont.)

- What's the best way to store text strings for data that we will not know until run time and that could be short or long?
- Dynamically:
  - Better memory usage
  - Requires a bit more coding




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


int main()
{
  // store 10 user names
  //   names type is still char **
  char* names[10];

  char temp_buf[40];
  for(int i=0; i < 10; i++){
    cin >> temp_buf;
    // Find length of strings
    int len = strlen(temp_buf);
    names[i] = new char[len + 1];
    strcpy(names[i], temp_buf);

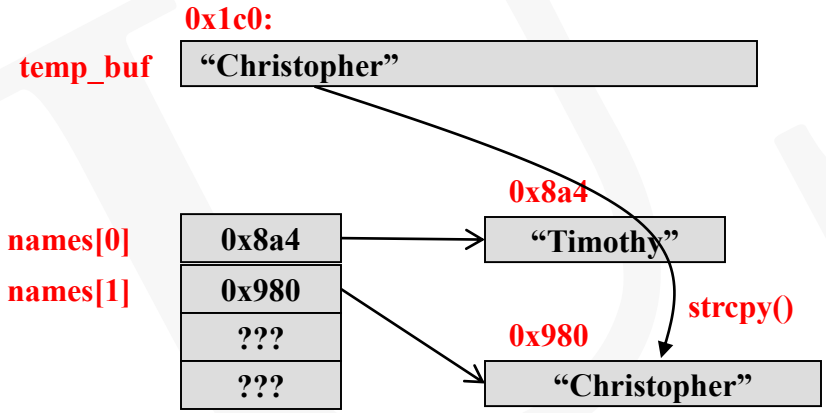
  }

  // Do stuff with names


  for(int i=0; i < 10; i++){
    delete [] names[i];
  }

  return 0;
}
```

More Dealing with Text Strings (cont.)



i=1

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


int main()
{
  // store 10 user names
  //   names type is still char **
  char* names[10];

  char temp_buf[40];
  for(int i=0; i < 10; i++){
    cin >> temp_buf;
    // Find length of strings
    int len = strlen(temp_buf);
    names[i] = new char[len + 1];
    strcpy(names[i], temp_buf);

  }

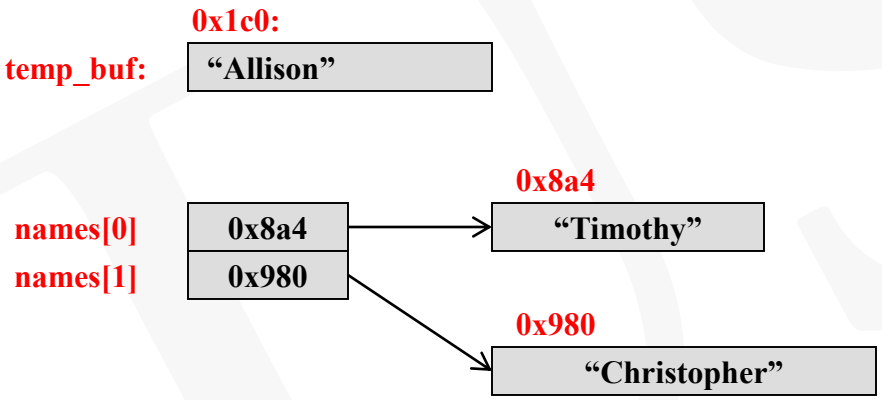
  // Do stuff with names


  for(int i=0; i < 10; i++){
    delete [] names[i];
  }

  return 0;
}
```

Shallow Copy vs. Deep Copy

- If we want to change the name, what do we have to do?
- Can we just use the assignment operator, '='?




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


int main()
{
  // store 10 user names
  //   names type is still char **
  char* names[10];

  char temp_buf[40];
  for(int i=0; i < 10; i++){
    cin >> temp_buf;
    names[i] = new char[strlen(temp_buf)+1];
    strcpy(names[i], temp_buf);

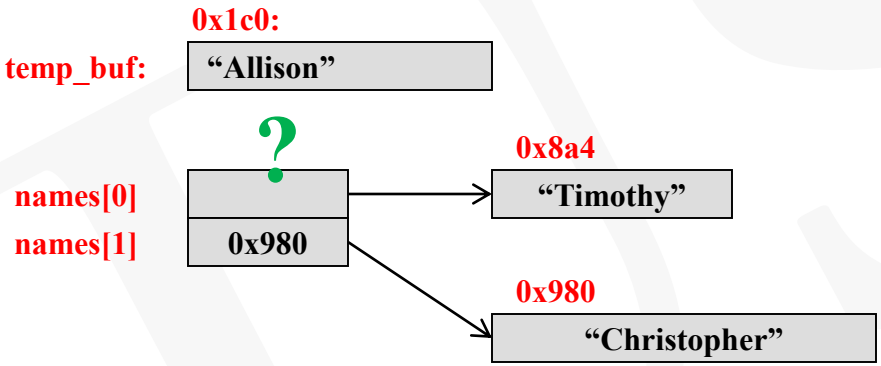
  }

  // What if I want to change names[0]&[1]

  cin >> temp_buf;  // user enters "Allison"
  names[0] = temp_buf;
  cin >> temp_buf;  // user enters "Jennifer"
  names[1] = temp_buf;

  for(int i=0; i < 10; i++){
    delete [] names[i];
  }
  return 0;
}
```

Shallow Copy vs. Deep Copy (cont.)




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


int main()
{
  // store 10 user names
  //   names type is still char **
  char* names[10];

  char temp_buf[40];
  for(int i=0; i < 10; i++){
    cin >> temp_buf;
    names[i] = new char[strlen(temp_buf)+1];
    strcpy(names[i], temp_buf);

  }

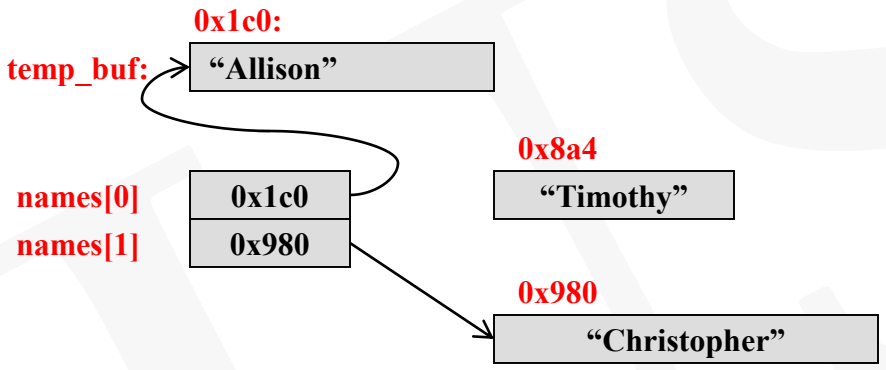
  // What if I want to change names[0]&[1]

  cin >> temp_buf;  // user enters "Allison"
  names[0] = temp_buf;
  cin >> temp_buf;  // user enters "Jennifer"
  names[1] = temp_buf;

  for(int i=0; i < 10; i++){
    delete [] names[i];
  }
  return 0;
}
```

Shallow Copy vs. Deep Copy (cont.)

- If we want to change the name, what do we have to do?
- Can we just use the assignment operator, '='?



temp_buf evaluates to address of array.
So names[0] = temp_buf simply copies address of array into names[0]…It does not make a copy of the array

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


int main()
{
  // store 10 user names
  //   names type is still char **
  char* names[10];

  char temp_buf[40];
  for(int i=0; i < 10; i++){
    cin >> temp_buf;
    names[i] = new char[strlen(temp_buf)+1];
    strcpy(names[i], temp_buf);

  }

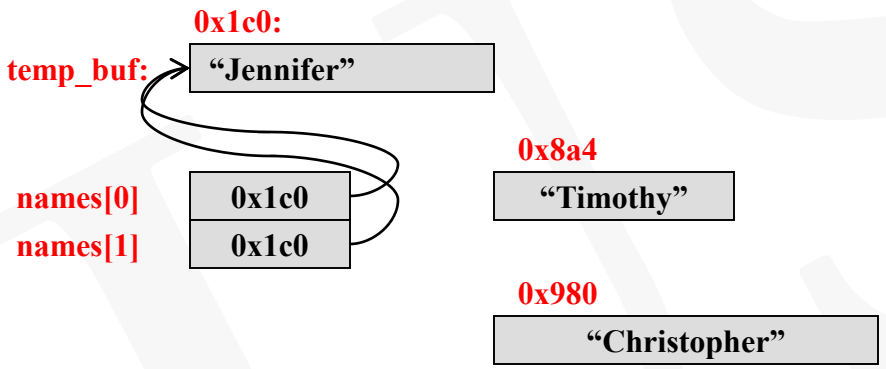
  // What if I want to change names[0]&[1]

  cin >> temp_buf;  // user enters "Allison"
  names[0] = temp_buf;
  cin >> temp_buf;  // user enters "Jennifer"
  names[1] = temp_buf;

  for(int i=0; i < 10; i++){
    delete [] names[i];
  }
  return 0;
}
```

Shallow Copy vs. Deep Copy (cont.)

- Pointers are references… assigning a pointer doesn't make a copy of what its pointing at it makes a copy of the pointer (a.k.a. "shallow copy")
  - Shallow copy = copy of pointers to data rather than copy of actual data



Same problem with assignment of temp_buf to names[1]. Now we have two things pointing at one array and we have lost track of memory allocated for Timothy and Christopher…**memory leak!**

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


int main()
{
  // store 10 user names
  //   names type is still char **
  char* names[10];

  char temp_buf[40];
  for(int i=0; i < 10; i++){
    cin >> temp_buf;
    names[i] = new char[strlen(temp_buf)+1];
    strcpy(names[i], temp_buf);

  }

  // What if I want to change names[0]&[1]

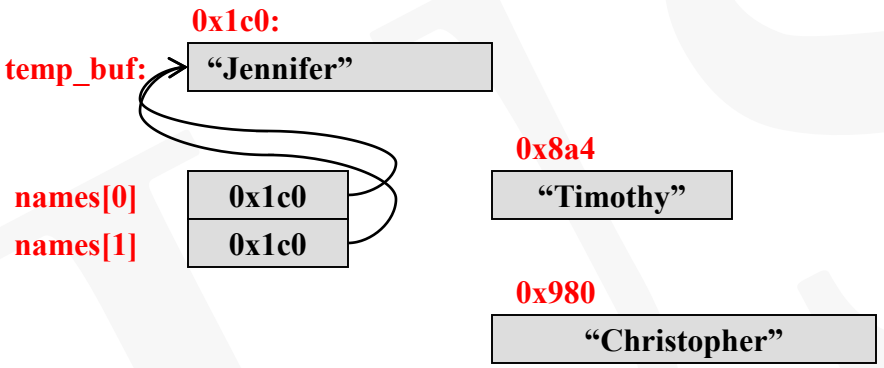
  cin >> temp_buf;  // user enters "Allison"
  names[0] = temp_buf;
  cin >> temp_buf;  // user enters "Jennifer"
  names[1] = temp_buf;

  for(int i=0; i < 10; i++){
    delete [] names[i];
  }
  return 0;
}
```

SHALLOW COPY

Shallow Copy vs. Deep Copy (cont.)

- Pointers are references... assigning a pointer doesn't make a copy of what it is pointing at



When we try to "delete" or free the memory pointed to by names[i], it will now try to return memory it didn't even allocate (i.e. temp_buf) and cause the program to crash!

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


int main()
{
  // store 10 user names
  //   names type is still char **
  char* names[10];

  char temp_buf[40];
  for(int i=0; i < 10; i++){
    cin >> temp_buf;
    names[i] = new char[strlen(temp_buf)+1];
    strcpy(names[i], temp_buf);

  }

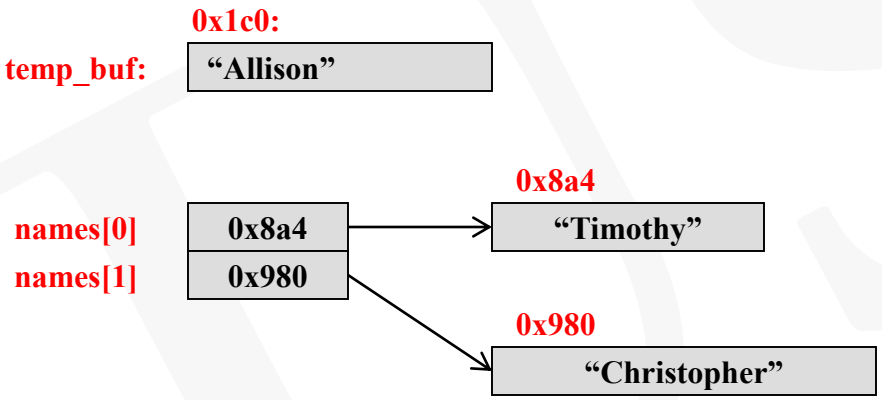
  // What if I want to change names[0]&[1]

  cin >> temp_buf;  // user enters "Allison"
  names[0] = temp_buf;
  cin >> temp_buf;  // user enters "Jennifer"
  names[1] = temp_buf;

  for(int i=0; i < 10; i++){
    delete [] names[i];
  }
  return 0;
}
```

Shallow Copy vs. Deep Copy (cont.)

- If we want to change the name, what do we have to do?
- Can we just use the assignment operator, '='? NO!
- Can we use strcpy()?




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


int main()
{
  // store 10 user names
  //   names type is still char **
  char* names[10];

  char temp_buf[40];
  for(int i=0; i < 10; i++){
    cin >> temp_buf;
    names[i] = new char[strlen(temp_buf)+1];
    strcpy(names[i], temp_buf);

  }

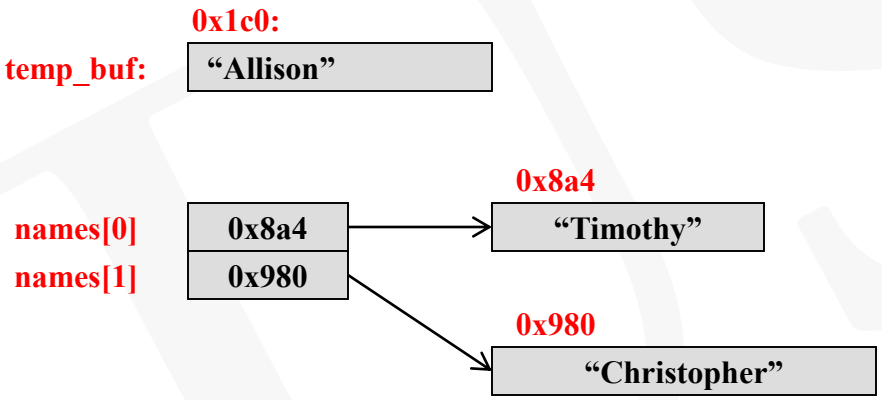
  // What if I want to change names[0]&[1]

  cin >> temp_buf;  // user enters "Allison"
  strcpy(names[0],temp_buf);
  cin >> temp_buf;  // user enters "Jennifer"
  strcpy(names[1], temp_buf);

  for(int i=0; i < 10; i++){
    delete [] names[i];
  }
  return 0;
}
```

Shallow Copy vs. Deep Copy (cont.)

- If we want to change the name, what do we have to do?
- Can we just use the assignment operator, '='? NO!
- Can we use strcpy()? Not alone...what if name is longer




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


int main()
{
  // store 10 user names
  //   names type is still char **
  char* names[10];

  char temp_buf[40];
  for(int i=0; i < 10; i++){
    cin >> temp_buf;
    names[i] = new char[strlen(temp_buf)+1];
    strcpy(names[i], temp_buf);

  }

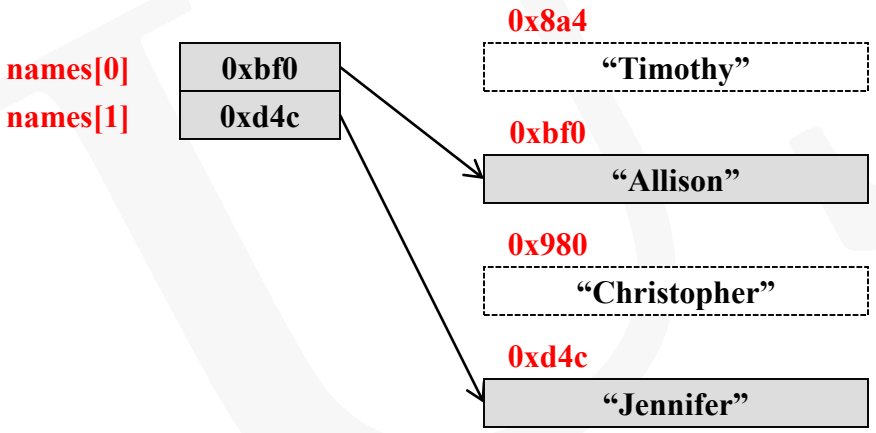
  // What if I want to change names[0]&[1]

  cin >> temp_buf;  // user enters "Allison"
  strcpy(names[0],temp_buf);
  cin >> temp_buf;  // user enters "Jennifer"
  strcpy(names[1], temp_buf);

  for(int i=0; i < 10; i++){
    delete [] names[i];
  }
  return 0;
}
```

Deep Copies

- If we want to change the name, what do we have to do?
- Must allocate new storage and copy original data into new memory (a.k.a. "deep copy")
  - Deep copy = Copy of data being pointed to into new memory




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


int main()
{
  // store 10 user names
  //   names type is still char **
  char *names[10];

  char temp_buf[40];
  for(int i=0; i < 10; i++){
    cin >> temp_buf;
    names[i] = new char[strlen(temp_buf)+1];
    strcpy(names[i], temp_buf);

  }

  // What if I want to change names[0]&[1]

  cin >> temp_buf;  // user enters "Allison"
  delete [] names[0];
  names[0] = new char[strlen(temp_buf)+1];
  strcpy(names[0], temp_buf);
  cin >> temp_buf;  // user enters "Jennifer"
  delete [] names[1];
  names[1] = new char[strlen(temp_buf)+1];
  strcpy(names[1], temp_buf);
  ...
```

DEEP COPY

END LECTURE

Practice

- 8 Index Cards:
  - Number 800,804,808,...832 in upper left
  - int x = 1298; char y='a';
    float z = 5.375;
    int dat[2] = {107,43};
    - Variable name in upper right, value in middle
- Practice '&' operator
  - `&x` => ??,
  - `&y` => ??,
  - `&z` => ??,
  - `&dat[1]` = ??;
  - `dat` => ??
- Practice '*' operator
  - `*(800)`,
  - `*(812)`,
- Pointer variable decl.
  - Take cards for 820,824
  - int *ptr1 = &x;
    ptr1 = &dat[1];
    ptr1 = dat;
  - double *ptr2;
    ptr2 = &z;
- Dereference practice
  - int a = 5;
    a = a + *ptr1;
  - (*ptr1)++;
  - *ptr2 = *ptr1 - *ptr2;
- Pointer Arithmetic
  - int *ptr = dat; ptr = ptr + 1;
  - // address in ptr was incremented by 4
  - ptr1++; // ptr1 now points at dat[1]
  - (*ptr1)++; // dat[0] = 108
  - x=*ptr1++; // x = dat[1] = 43 then inc. ptr1 to
    *(ptr1-2)++; // dat[0] = 109
  - 0x20bd8

Practice (cont.)

- Pointer Arithmetic
  - int *ptr1 = dat; ptr1 = ptr1 + 1;
  - // address in ptr was incremented by 4
  - ptr1++; // ptr1 now points at dat[1]
  - (*ptr1)++; // dat[0] = 108
  - x=*ptr1++; // x = dat[1] = 43 then inc. ptr1 to
  - Ptr1 = ptr1-2;
- Pointers to Pointers
- 2 New Cards
  - int *myptr = &dat[0];
  - int **ourptr = &myptr;
  - x = *myptr;
  - x = (**ourptr) + 1;
  - x = *(*ourptr + 1);

Arrays of pointers

- We often want to have several arrays to store data
  - Store several text strings
- Those arrays may be related, i.e., scores of students in a class

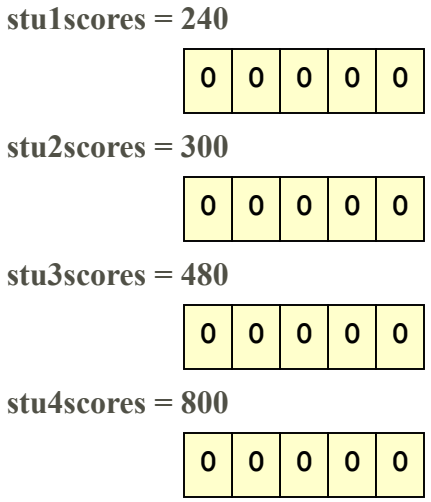
```
int stu1scores[5] = {0,0,0,0,0};
int stu2scores[5] = {0,0,0,0,0};
int stu3scores[5] = {0,0,0,0,0};
int stu4scores[5] = {0,0,0,0,0};

int main(int argc, char *argv[])
{
  int avg = 0;

  for(i=0;i < 5;i++) { avg += stu1scores[i]; }
  for(i=0;i < 5;i++) { avg += stu2scores[i]; }
  for(i=0;i < 5;i++) { avg += stu3scores[i]; }
  for(i=0;i < 5;i++) { avg += stu4scores[i]; }
  avg /= 4*5;

}
```

Painful



Activity

- Write a program that
  - Defines a function that accepts an integer, len as input and then generates an array of len random integers in the range [00-99] and returns it to the caller
  - From main ask the user for len via cin, call your function and "store" the return result
  - Iterate over the array returned by your function and average the values
  - Print that average...is that value close to _____ (expected value)?
  - Should the array be locally allocated or dynamically?
  - Go back & have len be entered from the command line