CS103 Unit 6 - Pointers

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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 Use Pointers

- [All of these will be explained as we go…]
- 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 a specific location in the computer (i.e. hardware devices)
  - Useful for embedded systems programming

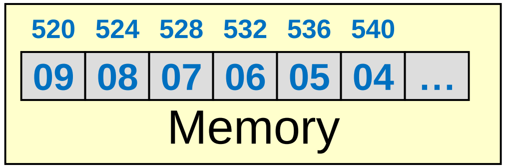
Pointer Analogy

- Imagine a set of 18 safe deposit or PO boxes each with a number
- There are 8 boxes with gold jewelry 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

- Pointers are references to other things
  - Really pointers are the address of some other variable in memory
  - "things" can be data (i.e. int's, char's, double's) 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)
  - URLs (www.usc.edu is a pointer to a physical HTML file on some server) and can be used in any other page to "point to" USC's website



520 is a "pointer" to the integer 9
536 is a "pointer" to the integer 5

Prerequisites: Data Sizes, Computer Memory

POINTER BASICS

Review Questions

- T/F: The elements of an array are stored contiguously in memory
  - ________________
- When an array is declared (i.e. `int dat[10]`) and its name is written by itself (e.g. cout << `dat;`) in an expression, it evaluates to what?
  - ______________________________

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

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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 => ??`

20bc0	00	
20bc4	30	x
20bc8	'a'	y
20bcc	5.375	z
20bd0	107	dat[0]
20bd4	43	dat[1]
20bd8	00	
20bdc	00	
20be0	00	
…	…	…

Memory

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 => 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

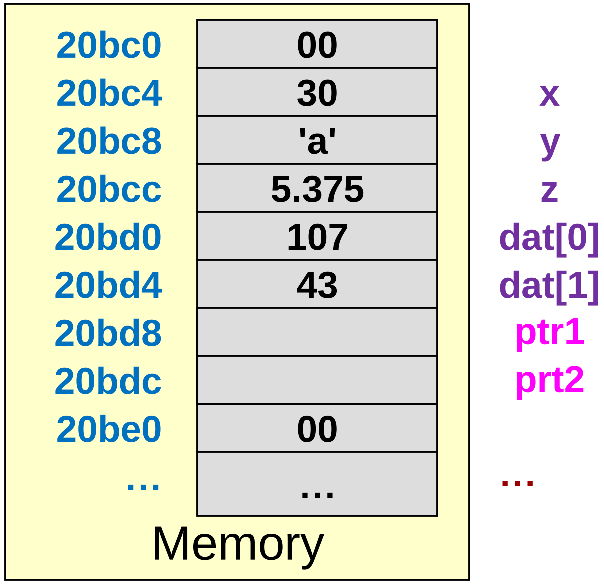
20bc0	00	
20bc4	30	x
20bc8	'a'	y
20bcc	5.375	z
20bd0	107	dat[0]
20bd4	43	dat[1]
20bd8	00	
20bdc	00	
20be0	00	
…	…	…

Memory

Pointers

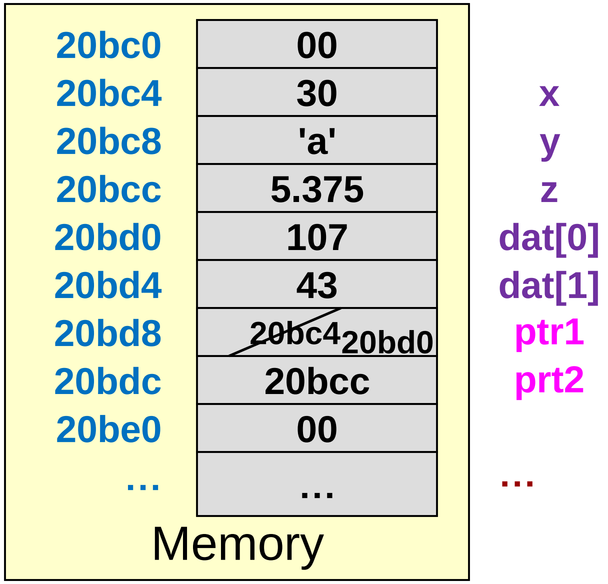
- Just as we declare variables to store int's and double's, we can declare a pointer ***variable*** to store the "address-of" (or "pointer-to") another variable
  - Requires 4-bytes of storage in a 32-bit system or 8-bytes in a 64-bit systems
  - Use a * after the type to indicate this a pointer variable to that type of data
    - More on why this syntax was chosen in a few slides…
- Declare variables:

```
– int x = 30;   char  y='a';
  float z = 5.375;
  int dat[2] = {107,43};
– int *ptr1;
  ptr1 = &x;         // ptr1 = ______________
  ptr1 = &dat[0];    // Change ptr1 = ______________
  // i.e. you can change what a pointer points to
– float *ptr2 = &z; // ptr2 = ___________
```



Pointers

- Just as we declare variables to store int's and double's, 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
    - More on why this syntax was chosen in a few slides…
- 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 += 1;   // *ptr = *ptr + 1;
    ```
  - ```
    *ptr2 = *ptr1 - *ptr2;
    ```

Address	Memory	Variable
20bc0	00	x
20bc4	30	y
20bc8	'a'	z
20bcc	5.375	dat[0]
20bd0	107	dat[1]
20bd4	43	ptr1
20bd8	20bd0	prt2
20bdc	20bcc	a
20be0		…
…	…	
    ```

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 stored in foo' (not 'value of foo' or 'value of address of foo')
- By the URL analogy, using the * operator on a pointer is like "clicking on a URL" (follow the link)
- Examples:
  - ```
    ptr1 = dat;
    int a = *ptr1 + 5;      // a = 112 after exec.
    ```
  - ```
    *ptr1 += 1;             // 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

20bc0	00	
20bc4	30	x
20bc8	'a'	y
20bcc	5.375	z
20bd0	~~107~~ 108	dat[0]
20bd4	43	dat[1]
20bd8	20bd0	ptr1
20bdc	20bcc	prt2
20be0	112	a
…	…	…

Memory
    ```

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

Pointer Questions

- Chapter 13, Question 6

```
int x, y;
int* p = &x;
int* q = &y;
x = 35; y = 46;
p = q;
*p = 78;
cout << x << " " << y << endl;
cout << *p << " " << *q << endl;
```

Prerequisites: Pointer Basics, Data Sizes

POINTER ARITHMETIC

Review Questions

- The size of an 'int' is how many bytes?
  - ____
- The size of a 'double' is how many bytes?
  - ____
- What does the name of an array evaluate to?
  - _________________
  - Given the declaration int dat[10], dat is an _____
  - Given the declaration char str[6], str is a _____
- In an array of integers, if dat[0] lived at address 0x200, dat[1] would live at…?
  - ____________

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 *ptr1 = dat; ptr1 = ptr1 + 1;`
    `// address in ptr was incremented by 4`
- Examples:
  - `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]

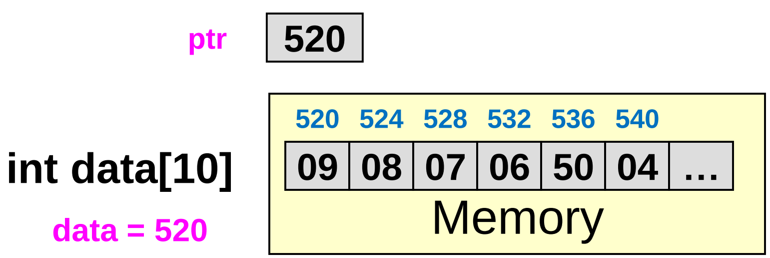
Address	Memory	Variable
20bc0	00	
20bc4	30	x
20bc8	'a'	y
20bcc	5.375	z
20bd0	107	dat[0]
20bd4	43	dat[1]
20bd8	20bd0	ptr1
20bdc	20bcc	prt2
20be0		a
…	…	…

Memory

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)   <=>   data[i]`
  - Both of these get the i-th value in an array
- We can use pointers and array names interchangeably:

```
– int data[10];             // data = 520;
– *(data + 4) = 50;         // data[4] = 50;
– int* ptr = data;          // ptr now points at 520 too
– ptr[1] = ptr[2] + ptr[3]; // same as data[1] = data[2] + data[3]
```



Arrays & Pointers

- Array names and 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

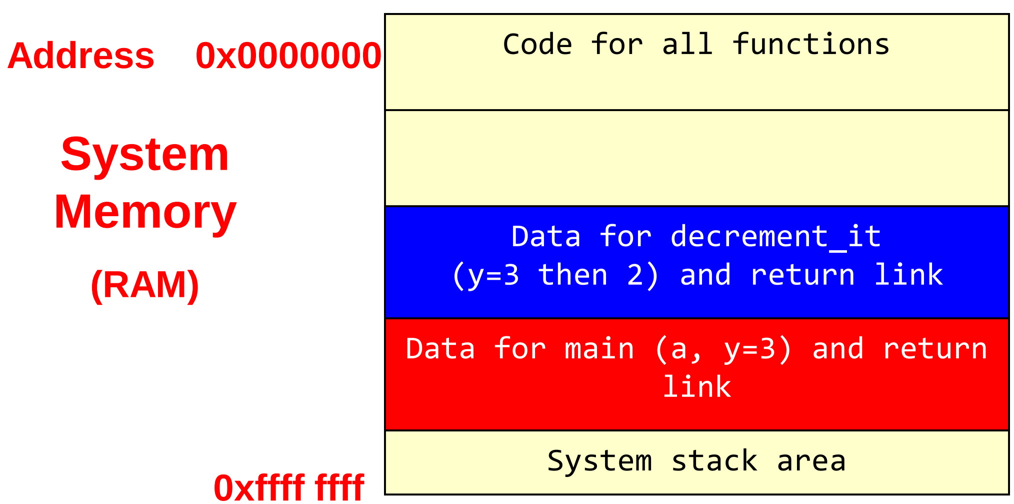
Pass by Value

- 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);

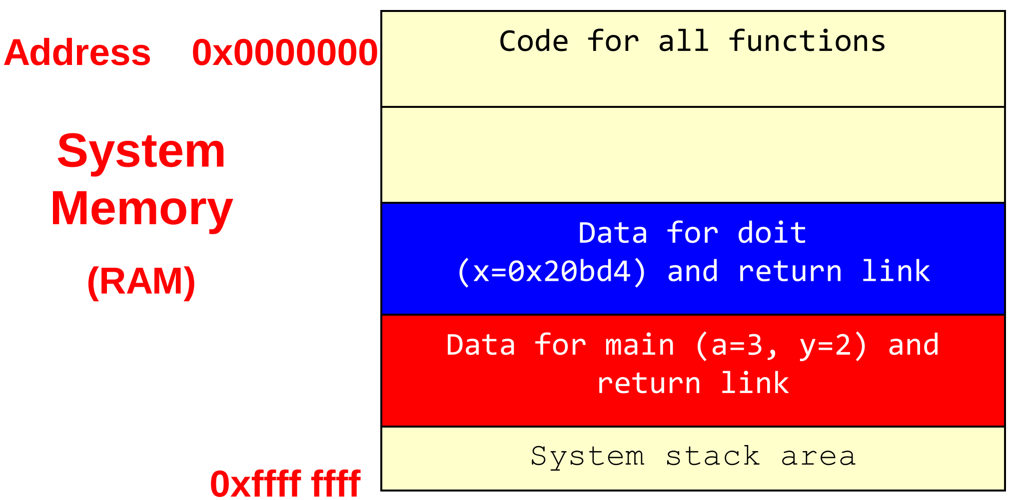
int main()
{
  int a, y = 3;
  decrement_it(y);
  cout << "y = " << y << endl;
}

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;
}

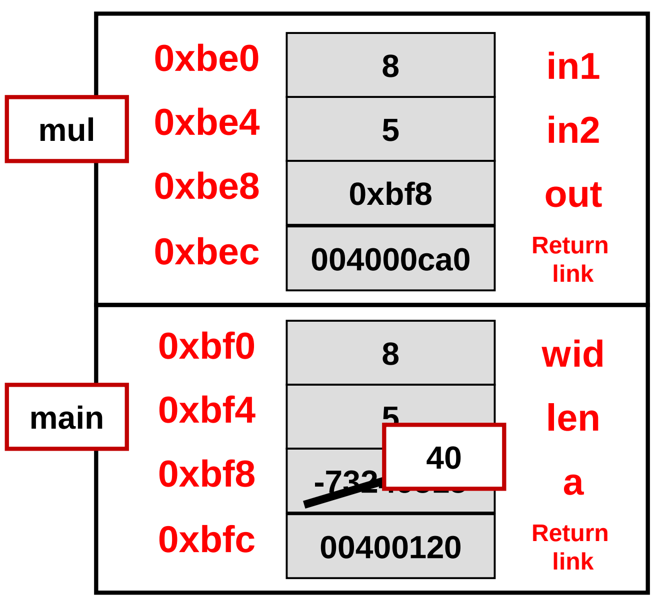
void swapit(int *x, int *y)
{  int temp;
   temp = *x;
   *x = *y;
   *y = temp;
}
```

program output: x=7,y=5

Correct Usage of Pointers

- Commonly functions will take some inputs and produce some outputs
  - We'll use a simple 'multiply' function for now even though we can easily compute this without a function
  - We could use the return value from the function but let's practice with pointers
- Can use a pointer to have a function modify the variable of another

Stack Area of RAM




```
// Computes the product of in1 & in2
int mul1(int in1, int in2);
void mul2(int in1, int in2, int* out);


int main()
{
  int wid = 8, len = 5, a;
  mul2(wid,len,&a);
  cout << "Ans. is " << a << endl;
  return 0;
}

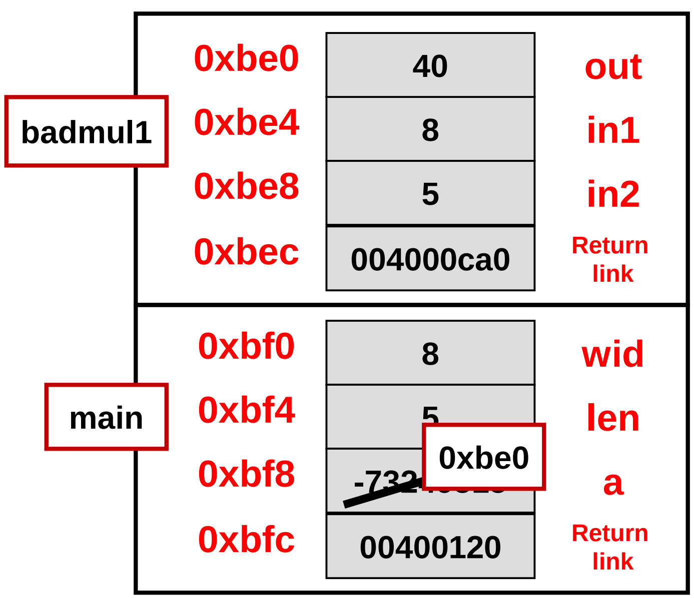
int mul1(int in1, int in2)
{
  return in1 * in2;
}

void mul(int in1, int in2, int* out)
{
  *out = in1 * in2;
}
```

Misuse of Pointers/References

- Make sure you don't return a pointer to a dead variable
- You might get lucky and find that old value still there, but likely you won't

Stack Area of RAM




```
// Computes the product of in1 & in2
int* badmul1(int in1, int in2);
int& badmul2(int in1, int in2);

int main()
{
  int wid = 8, len = 5;
  int *a = badmul1(wid,len);
  cout << "Ans. is " << *a << endl;
  return 0;
}

// Bad! Returns a pointer to a var.
// that will go out of scope
int* badmul1(int in1, int in2)
{
  int out = in1 * in2;
  return &out;
}
```

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

520	524	528	532	536	540	
09	08	07	06	05	04	…

Memory

```
void add_1_to_array_v1(int [], int);

void add_1_to_array_v2(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_v1(data);
  cout << “data[0]” << data[0] << endl;
  add_1_to_array_v2(data);
  cout << “data[0]” << data[0] << endl;
  return 0;

}

void add_1_to_array_v1(int my_array[], int size)
{
  int i=0;
  for(i=0; i < 10; i++){
    my_array[i]++;
  }
}

void add_1_to_array_v2(int *my_array, int size)
{
  int i=0;
  for(i=0; i < size; i++){
    my_array[i]++;
  }
}
```

520 520 520 520

Argument Passing Example

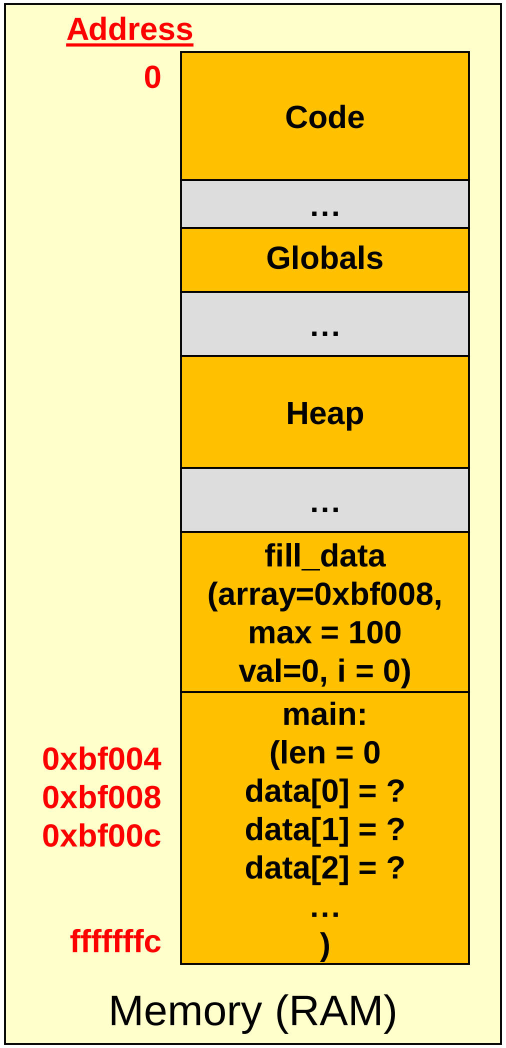
```
#include <iostream>
using namespace std;

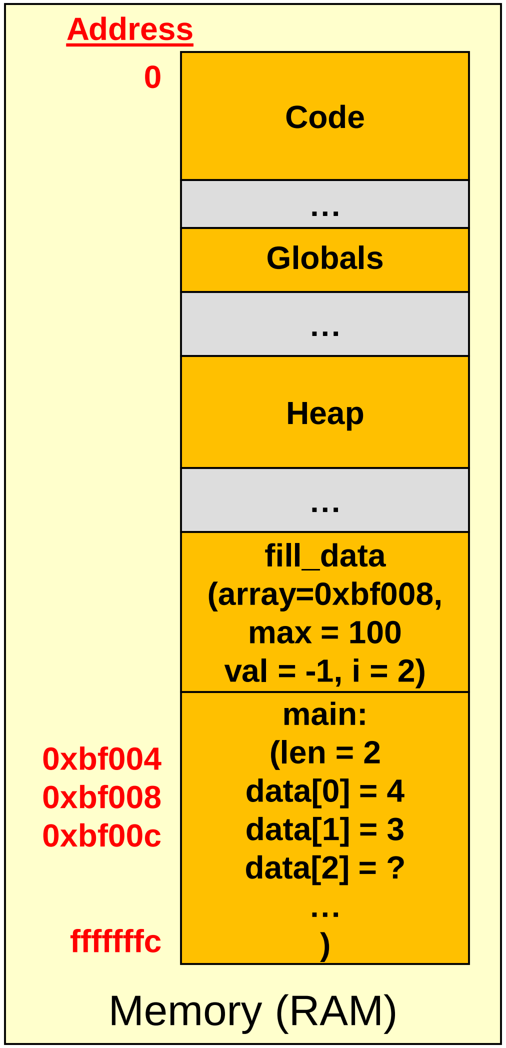
int main()
{
  int len=0;
  int data[100];

  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

- In class exercises
  - Roll2
  - Product

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

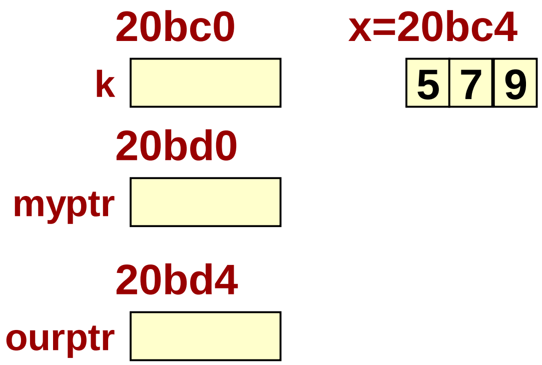
0 8	1 9	2 15	3 12	4 2	5 3
6 11	7 9	8 4	9 7	10 3	11
12 11	13 1	14 18	15 10	16 5	17 3

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=?`
  - `k = (**ourptr) + 1; // k=?`
  - `k = *(*ourptr + 1); // k+?`

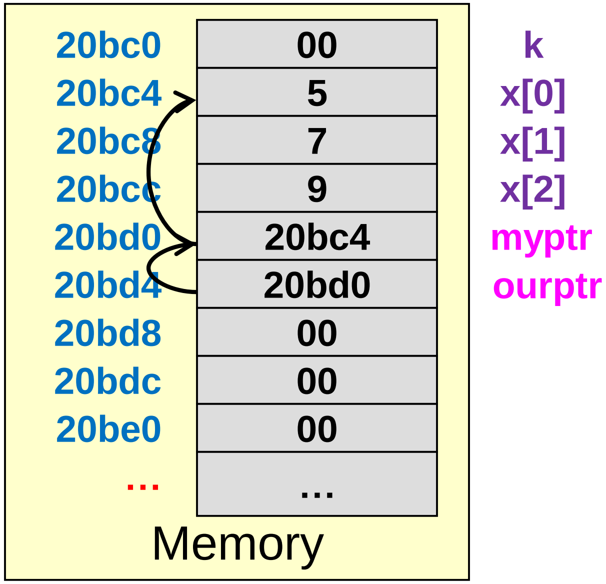
20bc0	00	k
20bc4	5	x[0]
20bc8	7	x[1]
20bcc	9	x[2]
20bd0		myptr
20bd4		ourptr
20bd8	00	
20bdc	00	
20be0	00	
…	…	

Memory



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=5`
  - `k = (**ourptr) + 1; //k=6`
  - `k = *(*ourptr + 1); //k=7`



To figure out the type 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*

Check Yourself

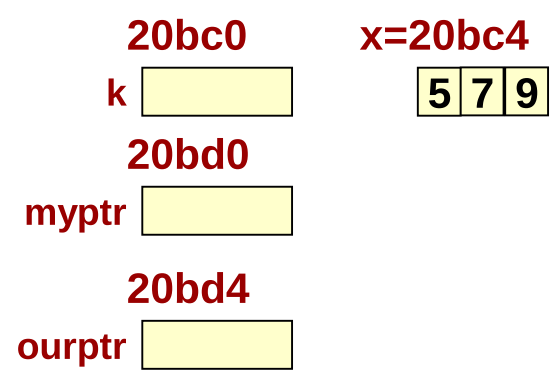
- Consider these declarations:
  - `int k, x[3] = {5, 7, 9};`
  - `int *myptr = x;`
  - `int **ourptr = &myptr;`
- Indicate the formal type that each expression evaluates to (i.e. `int`, `int *`, `int **`)

To figure out the type of data a pointer expression will yield…

- **Each * in the expression cancels a * from the variable type.**
- **Each & in the expression adds a * to the variable type.**

Orig. Type	Expr	Yields
myptr = int*	*myptr	int
ourptr = int**	**ourptr	int
	*ourptr	int*
k = int	&k	int*
	&myptr	int**

Expression	Type
&x[0]	
x	
&k	
myptr	
*myptr	
(*ourptr) + 1	
myptr + 2	
&ourptr	



Check Yourself

- Consider these declarations:
  - `int k,x[3] = {5, 7, 9};`
  - `int *myptr = x;`
  - `int **ourptr = &myptr;`

> - * in an expression yields a type with 1 less *
> - & yields a type with 1 more *

- Indicate the formal type that each expression evaluates to (i.e. int, int *, int **)

Expression	Type
`x[0]`	`int`
`x`	`int*`
`&k`	`int*`
`myptr`	`int*`
`*myptr`	`int`
`&myptr`	`int**`
`ourptr`	`int**`
`*ourptr`	`int*`
`myptr + 1`	`int*`

ARRAYS OF POINTERS AND C-STRINGS

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

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");
}
```

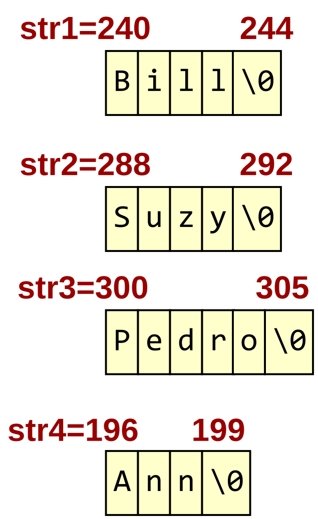
Arrays of pointers

- 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

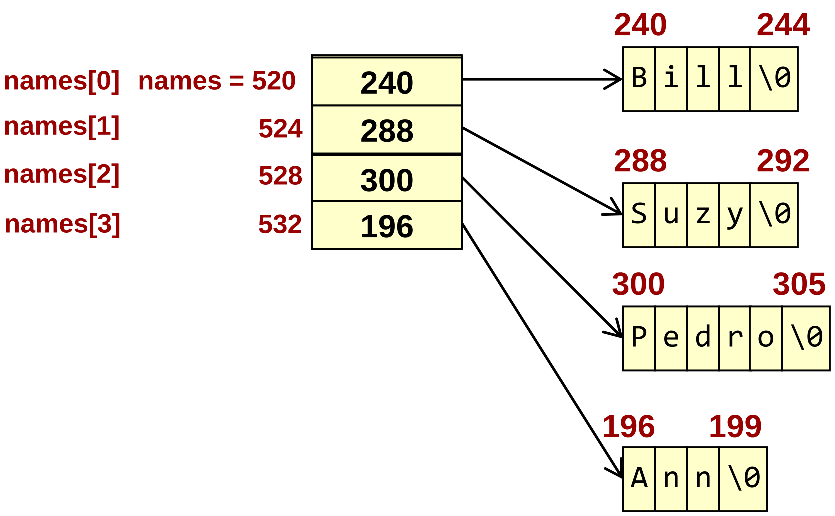
- We often want to have several arrays to store data
  - Store several text strings
- Those arrays may be related (i.e. all names of students in a class)
- What type is 'names'?
  - The address of the 0-th char* in the array
  - The address of a char* is really just a char**

```
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



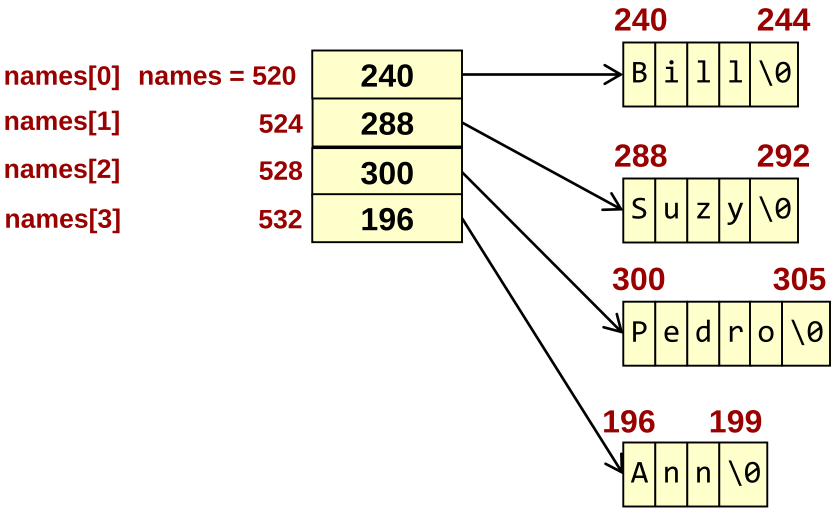
Arrays of pointers

- 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"};

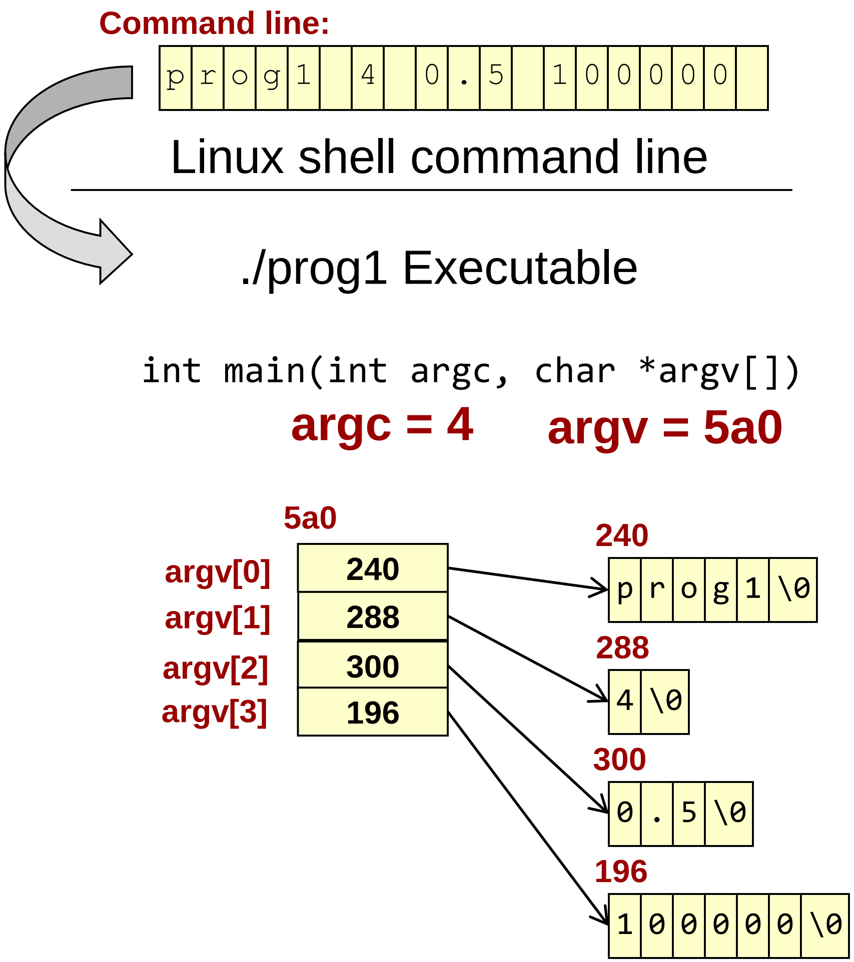
int main(int argc, char *argv[])
{
  int i;
  for(i=0; i < 4; i++){
    cout << names[i] << endl;
  }
  return 0;
}
```

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

- 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

argv[0]	p	r	o	g	1	\0	
argv[1]	4	\0					
argv[2]	0	.	5	\0			
argv[3]	1	0	0	0	0	0	\0

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

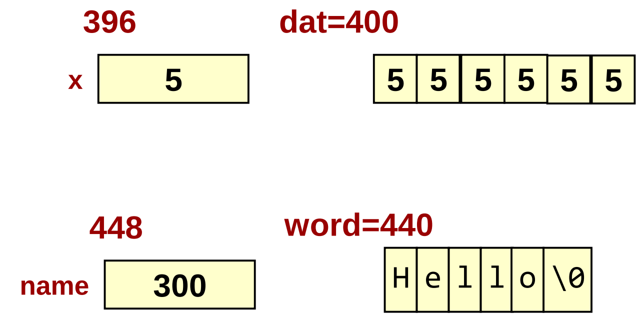
// char **argv is the same as char *argv[]
int main(int argc, char **argv)
{
  int init, num_sims;
  double p;
  if(argc < 4){
    cout << "usage: prog1 init p sims" << endl;
    return 1;
  }

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

  ...
```

cin/cout & char*s

- cin/cout determine everything they do based on the type of data passed
- cin/cout have a unique relationship with char*s
- When cout is given a variable of any type it will print the value stored in that exact variable
  - Exception: When cout is given a char* it will assume it is pointing at a C-string, go to that address, and loop through each character, printing them out
- When cin is given a variable it will store the input data in that exact variable
  - Exception: When cin is given a char* it will assume it is pointing at a C-string, go to that address, and place the typed characters in that memory




```
#include <iostream>
using namespace std;
int main()
{
  int x = 5, dat[10]; // dat is like an int*
  char word[10] = "Hello";
  char *name = word;

  cout << x << endl;        /* 5 */
  cout << dat << endl;      /* 400 */
  cout << word << endl;     /* Hello */
  cout << name << endl;     /* Hello */
  cout << name[0] << endl; /* H */
  cout << (void*) name << endl;  /* 440 */

  cin >> x;      /* Store into x (@396) */
  cin >> name;   /* Store string starting
                    at 440 */
  return 0;
}
```

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

- I 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
```

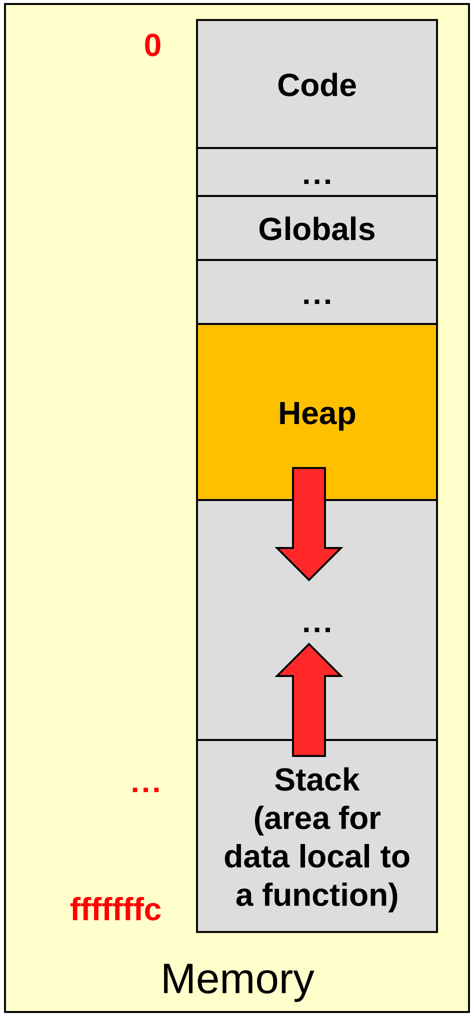
- Also, recall local variables die when a function returns
- We can allocate memory *dynamically* (i.e. at run-time)
  - **If we want memory to live beyond the end of a functions** (i.e. we want to control when memory is allocated and deallocated)
    - **This is the primary reason we use dynamic allocation**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

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 & 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 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;

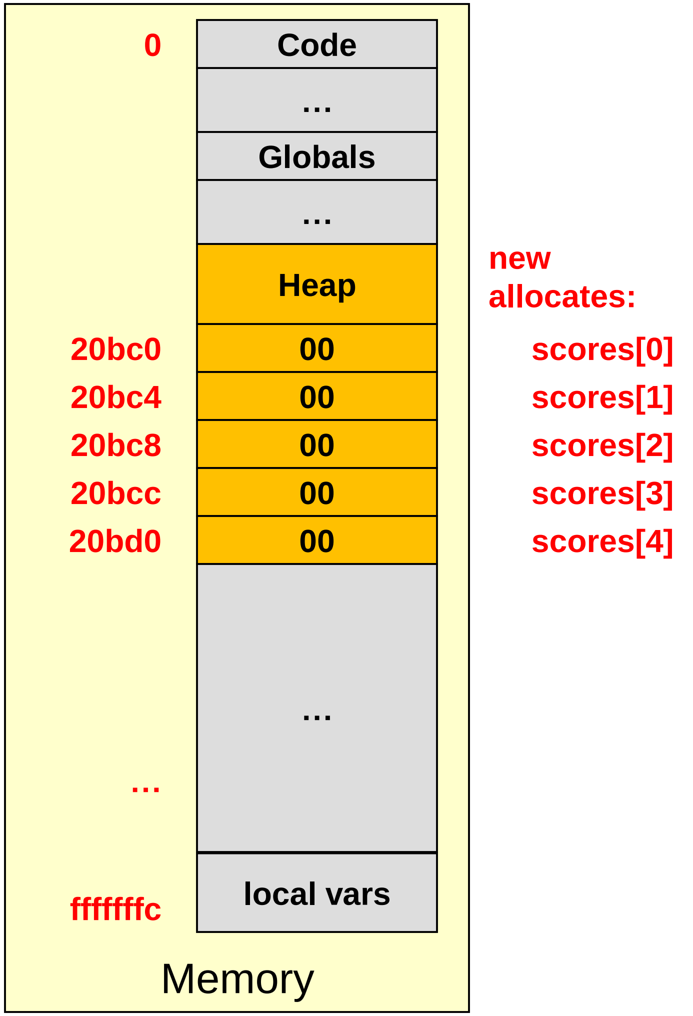
  cout << "How many students?" << endl;
  cin >> num;

  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

- __________ `data = new int;`
- __________ `data = new char;`
- __________ `data = new char[100];`
- __________ `data = new char*[20];`
- __________ `data = new string;`

Fill in the Blanks

- ____________ `data = new int;`
  - `int*`
- ____________ `data = new char;`
  - `char*`
- ____________ `data = new char[100];`
  - `char*`
- ____________ `data = new char*[20];`
  - `char**`
- ____________ `data = new string;`
  - `string*`

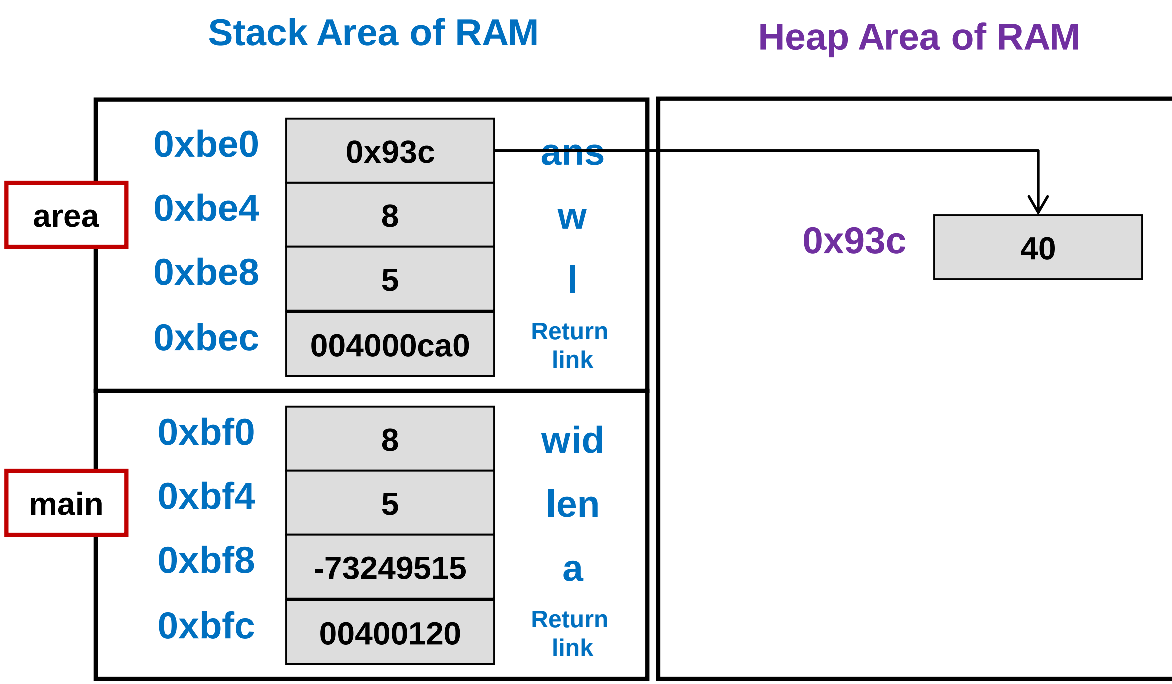
Dynamic Allocation

- 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)
- This code fails to save a pointer to the new int once area() finishes

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

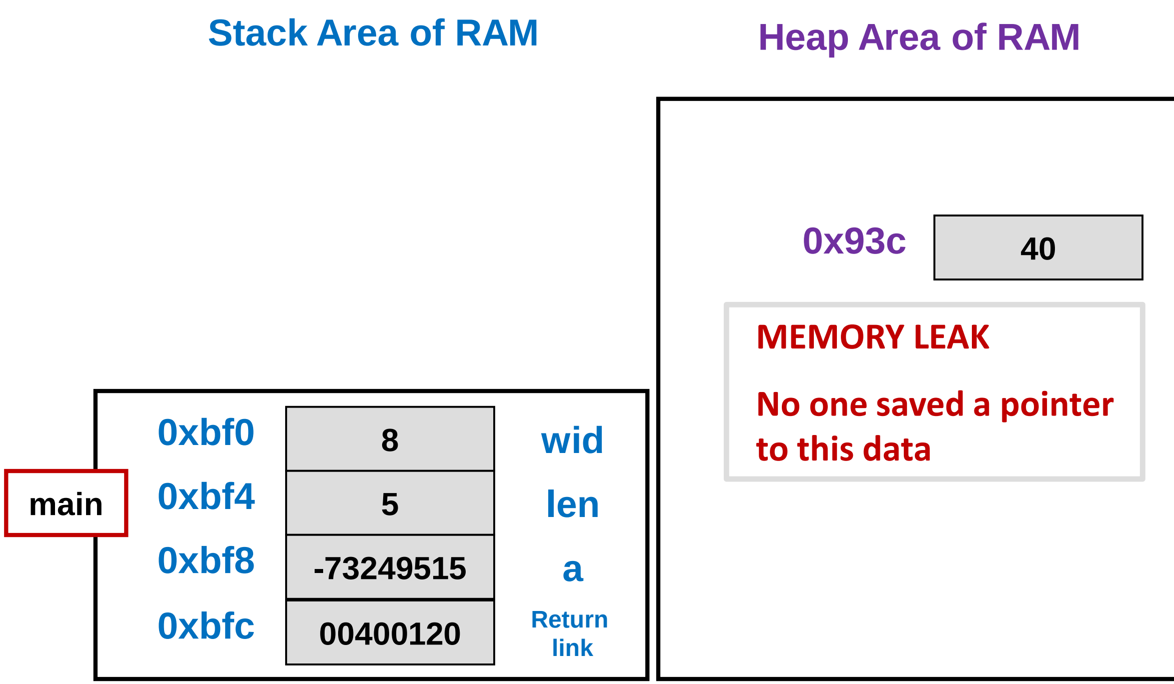
int main()
{
  int wid = 8, len = 5, a;
  area(wid,len);
}


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



Dynamic Allocation

- 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)
- This code fails to save a pointer to the new int once area() finishes




```
// 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;
}
```

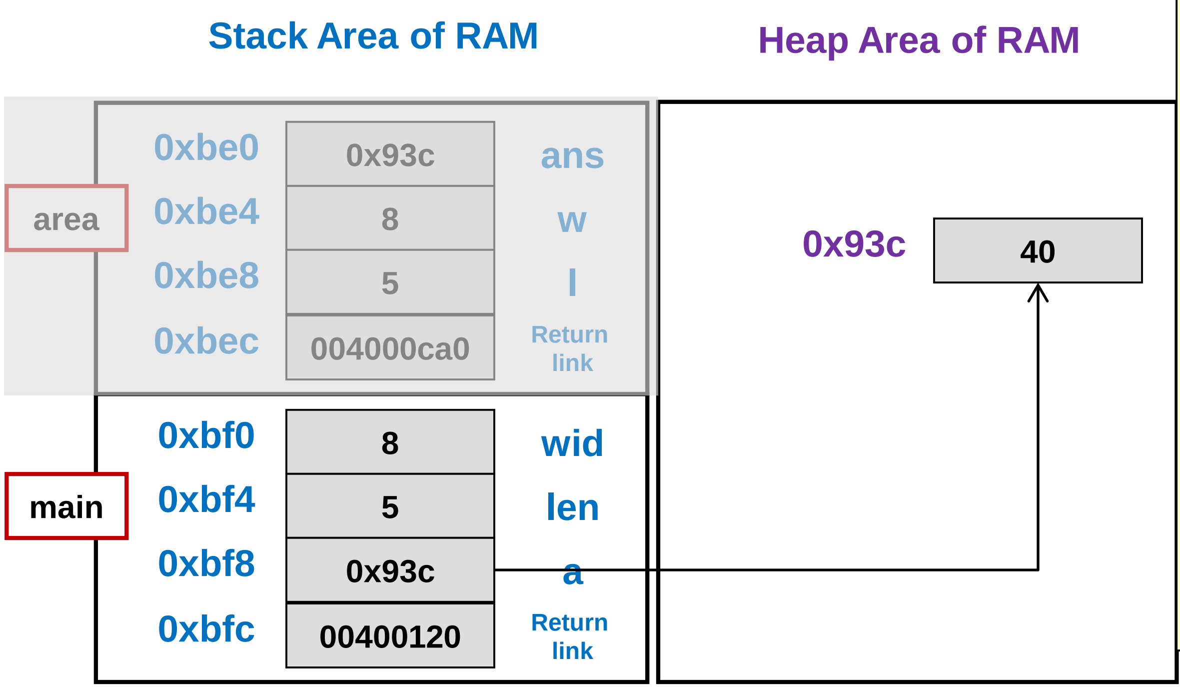
Dynamic Allocation

- 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)
- I must keep at least 1 pointer to dynamic memory at all times until I delete it

```
// 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; // 40

}

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



Pointer Mistake

- **Never** return a pointer to a local variable

```
// 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;
}

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

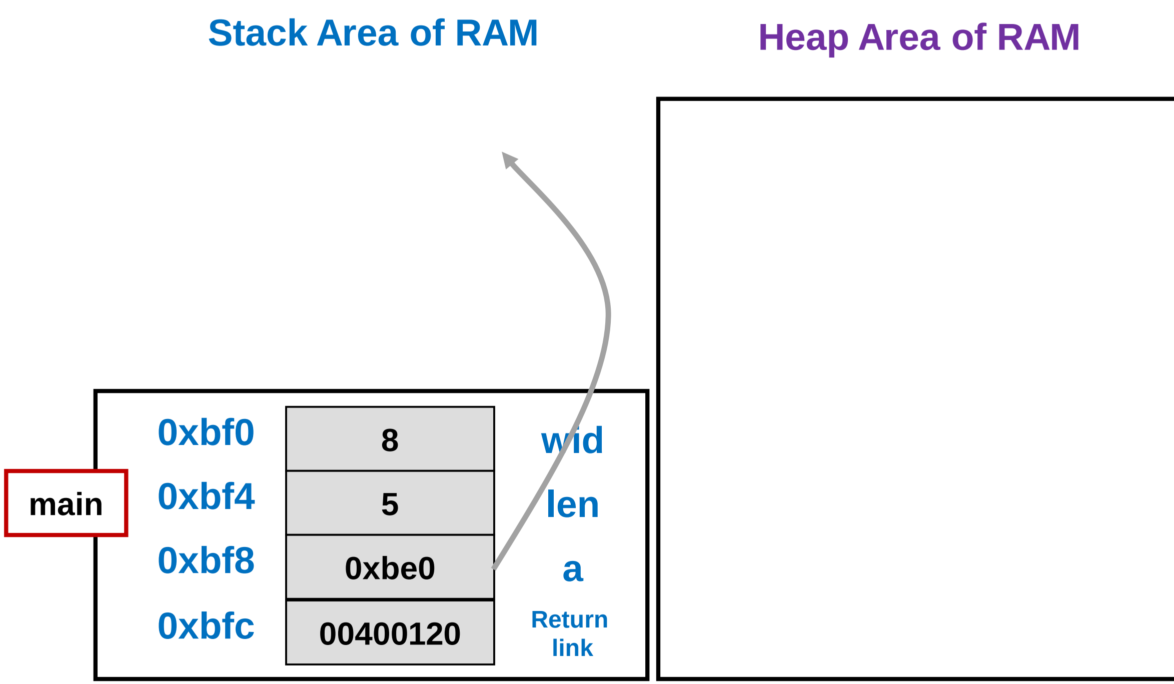
Stack Area of RAM

area	0xbe0	40	ans
	0xbe4	8	w
	0xbe8	5	l
	0xbec	004000ca0	Return link
main	0xbf0	8	wid
	0xbf4	5	len
	0xbf8	-73249515	a
	0xbfc	00400120	Return link

Heap Area of RAM

Pointer Mistake

- **Never** return a pointer to a local variable
- Pointer will now point to dead memory and the value it was pointing at will be soon corrupted/overwritten
- We call this a dangling pointer (i.e. a pointer to bad or dead memory)




```
// 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;
}


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

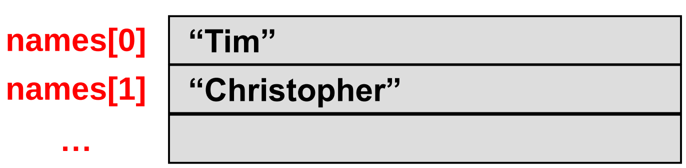
Exercises

- In-class-exercises
  - ordered_array

SHALLOW VS. DEEP COPY

Dealing with Text Strings

- 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?
- Statically:
  - Bad! Either wastes space or some user will enter a string just a little too long




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

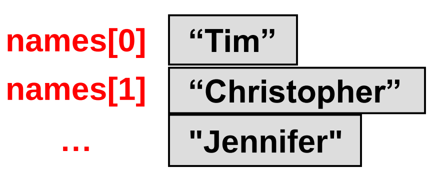
int main()
{
  // store 10 user names of up to
  // 40 chars
  char names[10][40];




}
```

Jagged 2D-Arrays

- 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



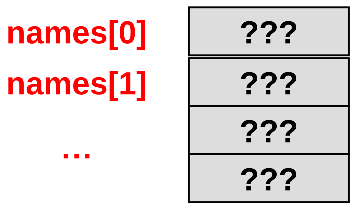

```
#include <iostream>
using namespace std;

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

  for(int i=0; i < 10; i++){
    /* read in and store each name */
  }
}
```

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 make up a URL like: 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* names[10];

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

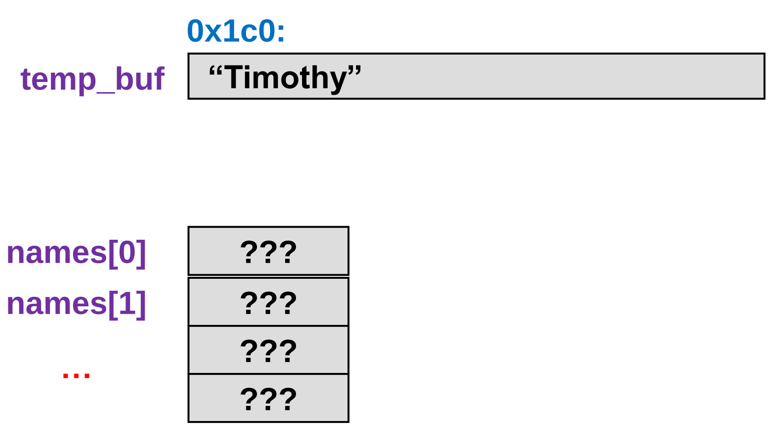
  // Do stuff with names



  return 0;
}
```

More Dealing with Text Strings

- 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];

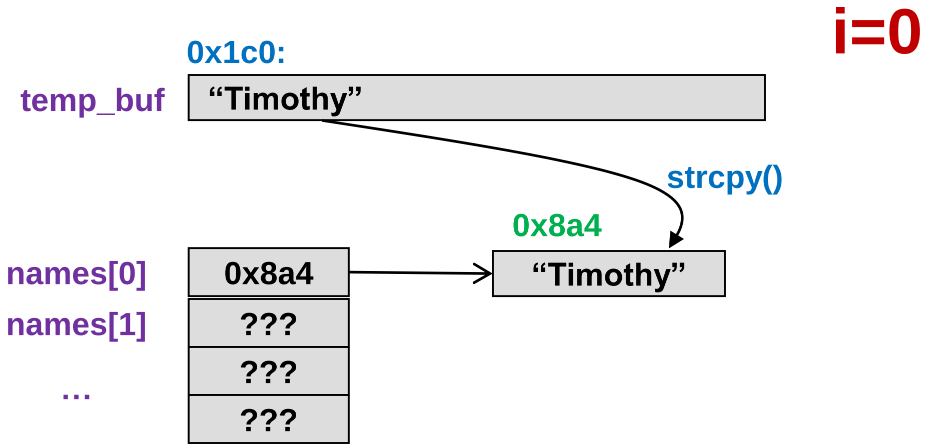
  // One "scratchpad" array to read in a name
  char temp_buf[40];

  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

- 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);

  }

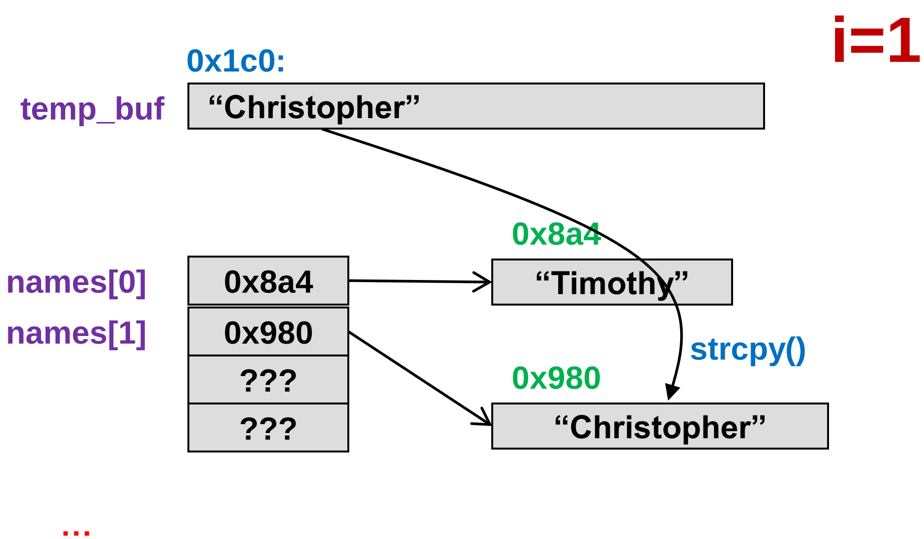
  // Do stuff with names


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

  return 0;
}
```

More Dealing with Text Strings

- 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);

  }

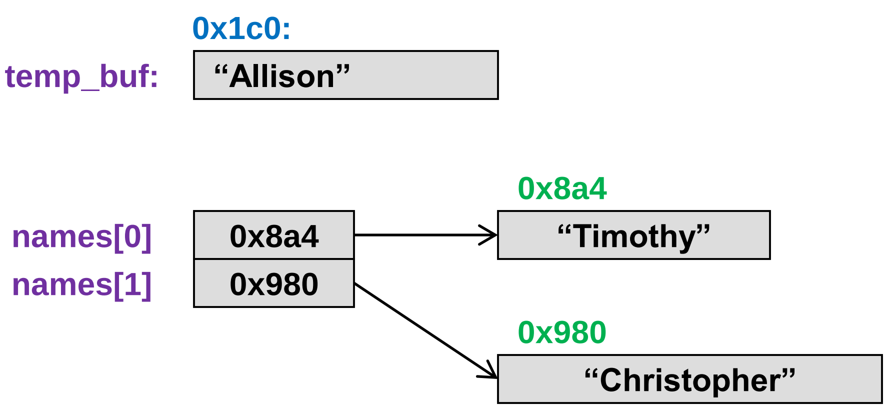
  // Do stuff with names


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

  return 0;
}
```

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);
  }

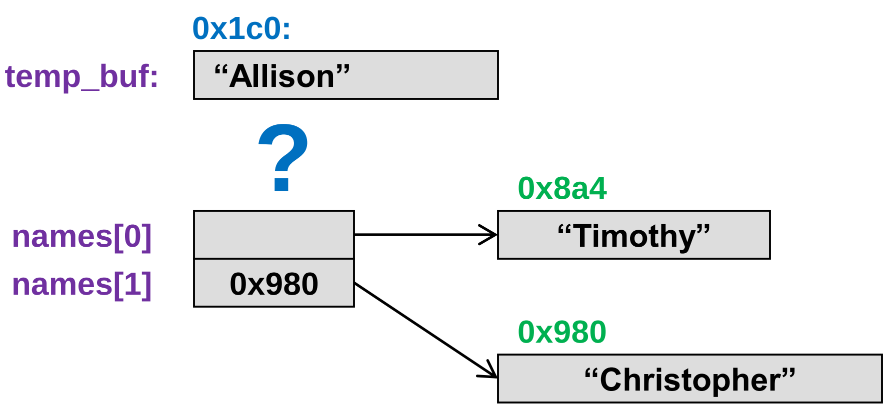
  // What if I want to change names[0] & [1]

  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

- 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);

  }

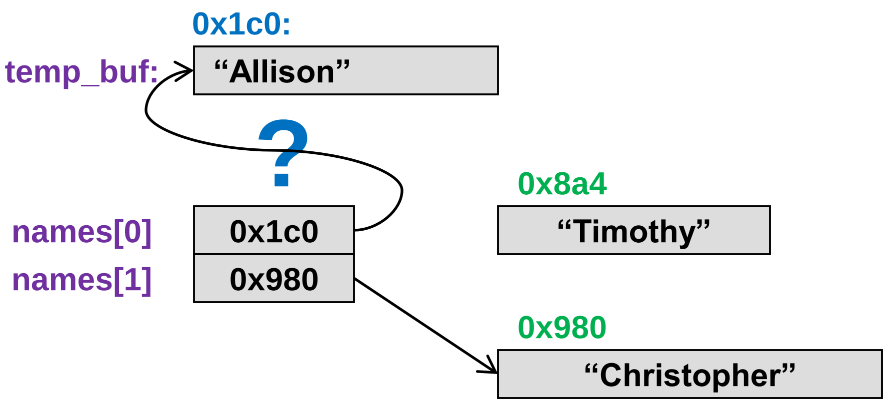
  // What if I want to change names[0] & [1]

  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

- 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);

  }

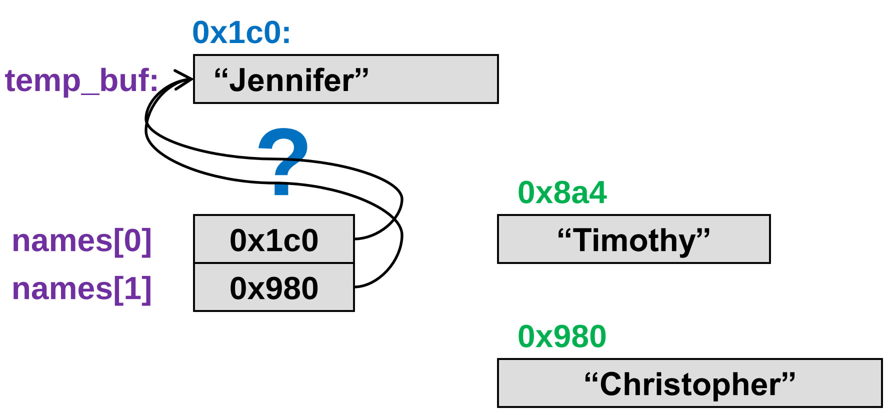
  // What if I want to change names[0] & [1]

  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

- 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…<u>memory leak!</u>

```
#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]

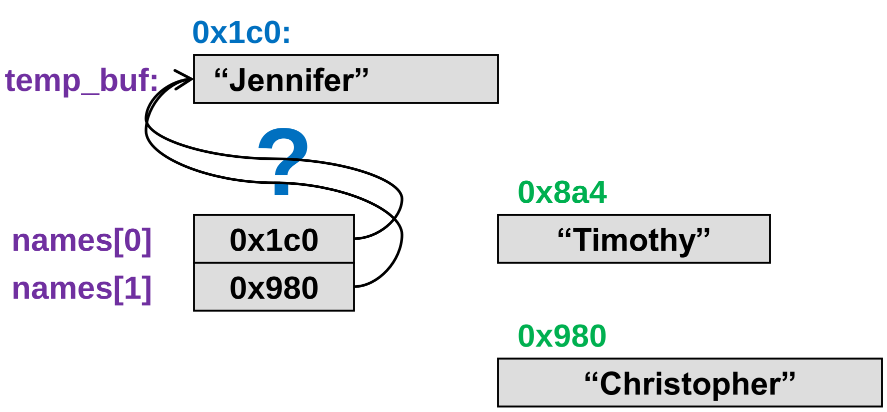
  cin >> temp_buf;  // user enters "Allison"
  names[0] = temp_buf;
  cin >> temp_buf;  // user enters "Jennifer"
  names[1] = temp_buf;

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

SHALLOW COPY

Shallow Copy vs. Deep Copy

- Pointers are references… assigning a pointer doesn't make a copy of what its pointing at
- Deleting the same memory **twice** will cause the program to **crash**



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);
  }

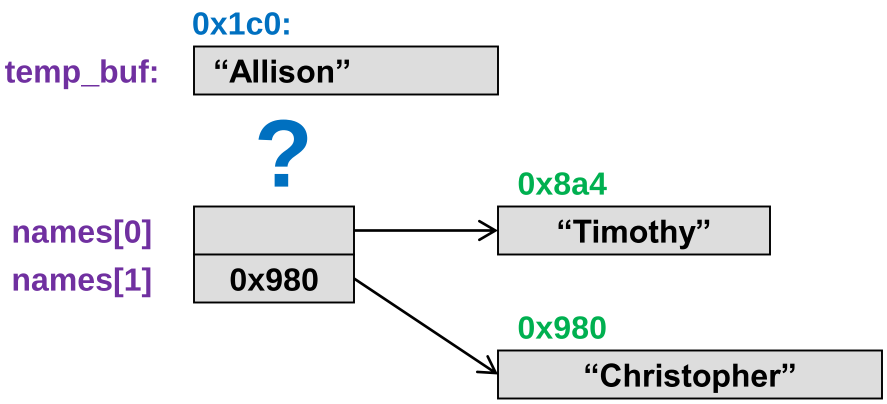
  // What if I want to change names[0] & [1]

  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

- Can we use strcpy() instead?




```
#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);

  }

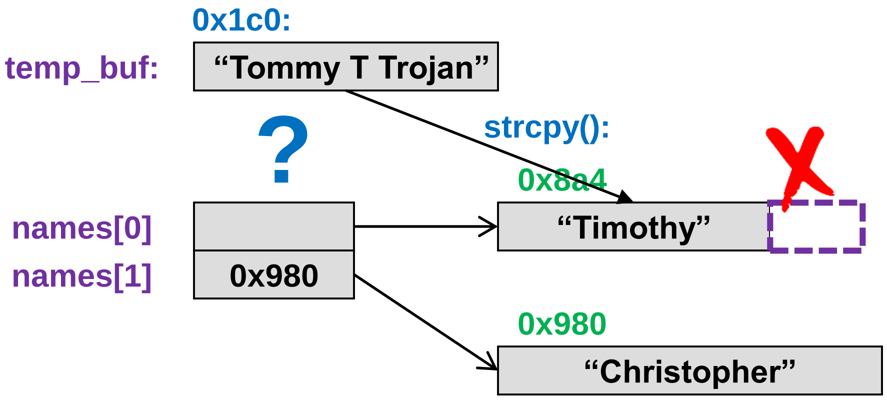
  // What if I want to change names[0] & [1]

  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

- Can we use strcpy() instead?
- **No!** Because what if the new name is **longer** than the array allocated for the old name…we'd write off the end of the array and corrupt 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);

  }

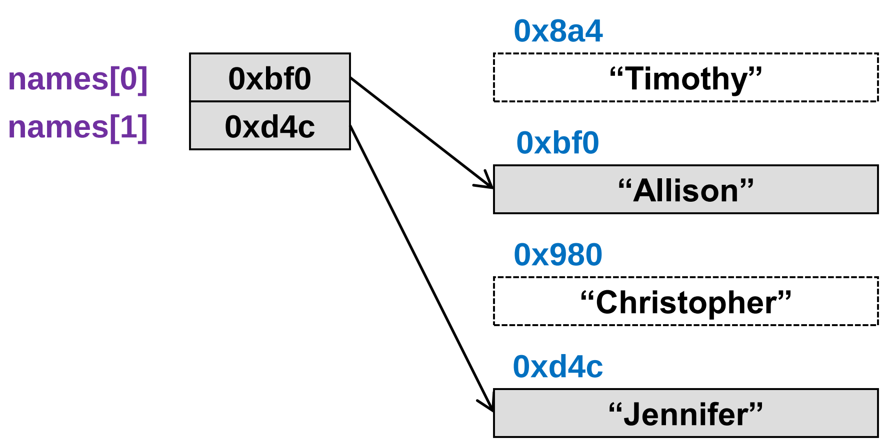
  // What if I want to change names[0] & [1]

  cin >> temp_buf;  // user enters "Allison"
  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** = allocate new memory AND then copy the original data (1 by 1) to the 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

Exercise

- In-class-exercises
  - nxmboard