C language

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Pointers/Dynamic Memory Allocation

Pointer Variable

- A variable that stores a memory address
  - Allows C programs to simulate call-by-reference
  - Allows a programmer to create and manipulate dynamic data structures
- Must be defined before it can be used
  - Should be initialized to NULL or valid address

Declaring Pointers

- Declaration of pointers

```
<type> *variable
<type> *variable = initial-value
```

- Examples:

```
int *x_ptr; // Not initialized
double *aPtr = NULL, *bPtr = NULL;
char *grade = NULL;
```

- A pointer variable has two associated values:

```c
char *grade = NULL;
```

  - Direct value
    * address of another memory cell
    * Referenced by using the variable name
  - Indirect value
    * value of the memory cell whose address is the pointer's direct value.
    * Referenced by using the indirection operator *

Pointer Operators

- Come before a variable name
  - * operator
    - Indirection operator or dereferencing operator
    - Returns a synonym, alias or nickname to which its operand points
  - & operator
    - Address of operator
    - Returns the address of its operand

- One way to store a value in a pointer variable is to use the & operator

```
int count = 5;
int *countPtr = &count;
```

  - The address of count is stored in *countPtr*
  - We say, *countPtr* points to *count*

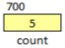
Pointers/Dynamic Memory Allocation

Pointer Variables

- Assume count will be stored in memory at location 700 and *countPtr* will be stored at location 300

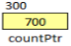
```
int count = 5;
```

causes 5 to be stored in count




```
int *countPtr = &count;
```

causes the address of count to be stored in *countPtr*



Pointer Variables

- We represent this graphically as

- The indirection/dereferencing operator is *

```
*countPrt = 10;
```

stores the value 10 in the address pointed to by *countPtr*

Pointer Variables

- The character * is used in two ways:
  1. To declare that a variable is a pointer
     - Pre-pending a variable with a * in a declaration declares that the variable will be a pointer to the indicated type instead of a regular variable of that type
  2. To access the location pointed to by a pointer
     - Pre-pending a variable with a * in an expression indicates the value in the location pointed to by the address stored in the variable

Simulating By Reference

- Invoked function uses * in formal parameters

```c
void increment(int *n){
    *n += 1; // or (*n)++;
}
```

- Invoking function uses & in actual parameters

```c
int count = 0;
increment(&count);
printf("%d\n", count); // Prints 1
```

Pointer Variables and Arrays

- Given

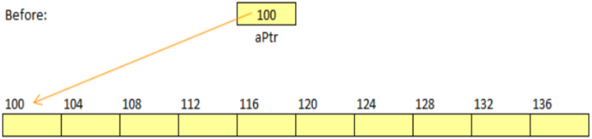
```
int x;
int xPtr = &x;
int *xPrt = 7;
```

- The compiler will know how many bytes to copy into the memory location pointed to by *xPtr*
- Defining the type that the pointer points to permits a number of other interesting ways a compiler can interpret code

Pointers/Dynamic Memory Allocation

Pointer Variables and Arrays

- Consider a block in memory consisting of ten integers of 4 bytes in a row at location 100_{10}
- Now, let's say we point an integer pointer *aPtr* at the first of these integers



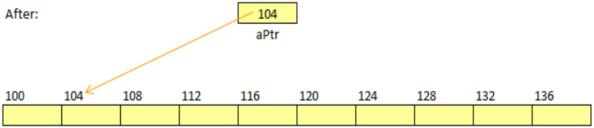
- What happens when we write

```
aPtr = aPtr + 1;
```

Pointers/Dynamic Memory Allocation

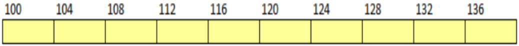
Pointer Variables and Arrays

- Because the compiler "knows"
  - This is a pointer (i.e. its value is an address)
  - That it points to an integer of length 4 at location 100
- Instead of 1, $aPtr = aPtr + 1;$ adds 4 to *aPtr*
  - Now aPtr "points to" the next integer at location 104
  - Same for: *aPtr+=1, aPtr++, and ++aPtr*



Pointer Variables and Arrays

- Since a block of 10 integers located contiguously in memory is, by definition, an array of integers, this brings up an interesting relationship between arrays and pointers



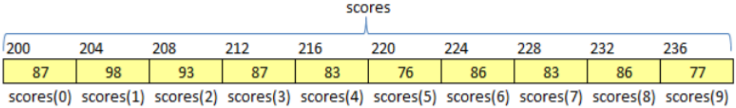
Pointers/Dynamic Memory Allocation

Pointer Variables and Arrays

- Consider this array allocated at location 200

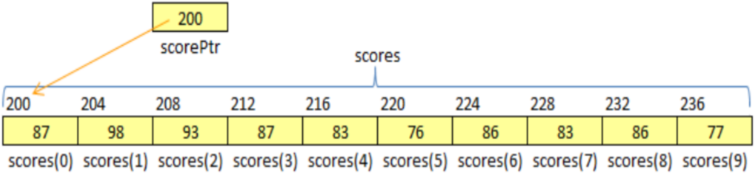
```
int scores[10] = {87, 98, 93, 87, 83, 76, 86, 83, 86, 77};
```

- We have an array containing 10 integers
- We refer to each of these integers by means of a subscript to scores
  - Using *scores[0]* through *scores[9]*



- The name of an array and the address of the first element in the array represent the same thing
- Consequently, we could alternatively access them via a pointer:

```
int scores[10] = {87, 98, 93, 87, 83, 76, 86, 83, 86, 77};
...
int *scorePtr = NULL;
...
scorePtr = &score[0]; //Points to first element
```

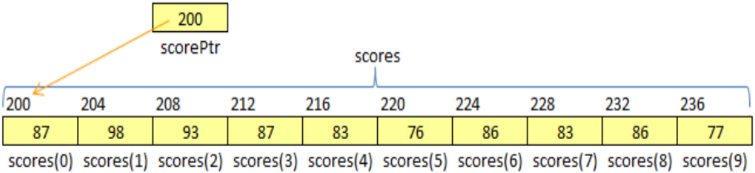


Pointers/Dynamic Memory Allocation

Pointer Variables and Arrays

- The name of an array is a pointer constant to the first element of the array
- So, we could also use:

```c
int scores[10] = {87, 98, 93, 87, 83, 76, 86, 83, 86, 77};
...
int *scorePtr = NULL;
...
scorePtr = score; //Points to array
```



- If *scorePtr* is pointing to a specific element in the array and n is an integer,

```
corePtr + n;
```

  is the pointer value n elements away

- We can access elements of the array either using the array notation or pointer notation
  - If *scorePtr* points to the first element, the following two expressions are equivalent:

```
scores[n]; // Array notation
*(scorePtr + n);  // Pointer notation
```

Pointers and Dynamic Allocation of Memory

- So far, we have always allocated memory for variables that are located on the **stack**
- We can access elements of the array either using the array notation or pointer notation
  - Size of such variables must be known at compile time
- Sometimes convenient to allocate memory at run time
  - System maintains a second storage area called the **heap**
  - Functions **calloc** and **malloc** allocate memory as needed of size needed

1. Use allocating function (such as **malloc()**, **calloc()**, etc.)
   - Returns void pointer
     * void * indicates a pointer to untyped memory
     * Will have to cast the returned value to the specific type needed
2. Use memory through the pointer notation
3. Release allocated space when no longer needed, so that it can be reused

Pointers and Dynamic Allocation of Memory: calloc

calloc

- Used to dynamically create an array in the heap
- Contiguous allocation
  - Initialized to binary zeros
- Must

```
#include <stdlib.h>
```

- Takes two arguments
  1. Number of array elements
  2. Amount of memory required for one element
     * Use sizeof function / operator
- Returns
  - Void pointer if successful
  - NULL if unsuccessful

Pointers and Dynamic Allocation of Memory: calloc

- Example 1: String

```
const int str_len = 500;
char *str_ptr = NULL;
...
str_ptr = (char *) calloc(str_len, sizeof(char));
if (str_ptr == NULL){
    printf("Halting: Unable to allocate string.\n");
    exit(1);
}
```

- Example 2: Integers

```
const int arraySize = 1000;
char *arrayPtr = NULL;
...
arrayPtr = (int *) calloc(arraySize, sizeof(int));
if (arrayPtr == NULL){
    printf("Halting: Unable to allocate array.\n");
    exit(1);
}
```

Pointers and Dynamic Allocation of Memory: malloc

malloc

- Used to dynamically get memory from heap
- Contiguous allocation
  - No initialization
- Must

```c
#include <stdlib.h>
```

- Takes one argument
  - Total amount of memory required
- Returns
  - Void pointer if successful
  - NULL if unsuccessful

Pointers/Dynamic Memory Allocation

Pointers and Dynamic Allocation of Memory: malloc

- Example 1: String

```c
const int str_len = 500;
char *str_ptr = NULL;
...
str_ptr = (char *) malloc(str_len);
if (str_ptr == NULL){
    printf("Halting: Unable to allocate string.\n");
    exit(1);
}
```

- Example 2: Integers

```c
const int arraySize = 1000;
char *arrayPtr = NULL;
...
arrayPtr = (int *) malloc(arraySize * sizeof(int));
if (arrayPtr == NULL){
    printf("Halting: Unable to allocate array.\n");
    exit(1);
}
```

Pointers and Dynamic Allocation of Memory: free

free

- Used to dynamically release memory back to heap
- Contiguous deallocation
- Must

```
#include <stdlib.h>
```

- Takes one argument
  - Pointer to beginning of allocated memory
- Good idea to also NULL pointer if reusing

Free up the memory => Increase the amount of Memory available !

Pointers and Dynamic Allocation of Memory: free

- Example:

```
const int arraySize = 1000;
char *arrayPtr = NULL;
...
arrayPtr = (int *) malloc(arraySize * sizeof(int));
if (arrayPtr == NULL){
    printf("Halting: Unable to allocate array.\n");
    exit(1);
}
...
free(arrayPtr);
arrayPtr = NULL;
```