

Data Structures

Function Calls in C++

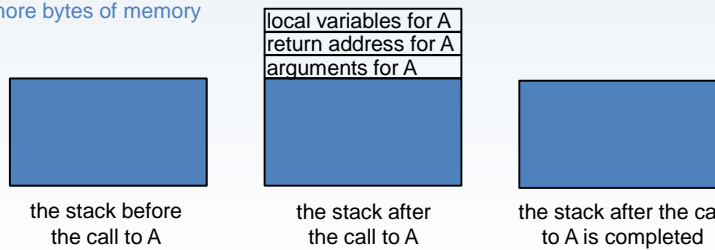
Dynamic Memory

Abstract Data Types

Function Calls and the Stack

- The stack is an area of memory that is used by a program to communicate with its functions.
- In particular, each time that a function is called, its arguments, its **return address** (the place where the program should return to after the function is finished), and the memory for its local variables are put on top of the stack as shown below.

Each rectangle represents one or more bytes of memory



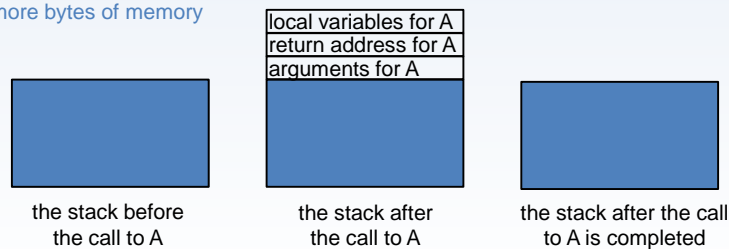
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Function Calls and the Stack

- When the function is finished, this information is removed from the stack.
- Notice that when a stack is used in this way, the memory needed for a function's arguments and local variables is **allocated** (that is, put on the stack), only when the function is executing.

Each rectangle represents one or more bytes of memory



The movement of the stack when function A is called

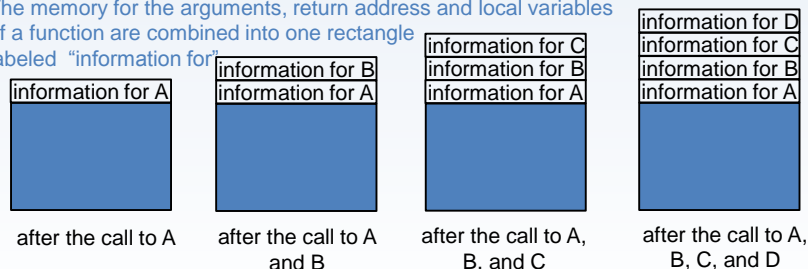
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Function Calls and the Stack

- Suppose that function A calls function B, which calls function C, which calls function D.
- This sequence of calls is an example of function **nesting**, and the number of calls in the sequence is called the **nesting depth**.
- The figure below shows how the stack grows when each successive call is made.

The memory for the arguments, return address and local variables of a function are combined into one rectangle labeled "information for"



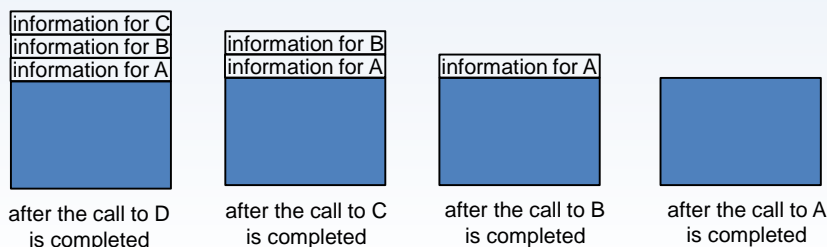
The movement of the stack when functions A, B, C, and D are called

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Function Calls and the Stack

- The figure below shows the movement of the stack when the calls are completed.
- In particular, notice that the functions A, B, C, and D are completed in the **reverse** order in which they are called.



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The movement of the stack after functions A, B, C, and D are completed
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Function Calls and the Stack

- We will see how a stack is implemented later.
- For now, we note that the amount of memory allocated to the stack is finite.
- It is possible, particularly with recursion (which we will also see later), to run out stack memory.
- This occurrence called **stack overflow**, usually causes the program to terminate.

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Function Calls in C++

C++ passes arguments to functions by value (pass-by-value).

For that reason, the called function cannot alter the value of a variable in the calling program.

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Function Calls in C++

- If the function has to make a change to a single value, this value can be passed back to the calling program with a **return** statement.

```
int add(int a, int b){
    .....
    return sum;
}
int result = add(5, 7);
```

What if the function has to change more than one value???

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Erroneous program: function only
swaps copies of a and b sent to it.

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

int main( )
{
    int a = 5, b = 6;
    swap(a, b);
    return 0;
}
```

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Correct Function

C STYLE

```
void swap(int *xptr, int *yptr){
    int temp;
    temp = *xptr;
    *xptr = *yptr;
    *yptr = temp;
}

int main( )
{
    int a = 5, b = 6;
    swap(&a, &b);
    return 0;
}
```

C++ STYLE

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

int main( )
{
    int a = 5, b = 6;
    swap(a, b);
    return 0;
}
```

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Pointers in different programming languages

- `int i = 5;`
- `int *ptr=&i; //C style`
- `int &j = i; //C++ style`
-
- `Integer i=new Integer(5); //Java Style`

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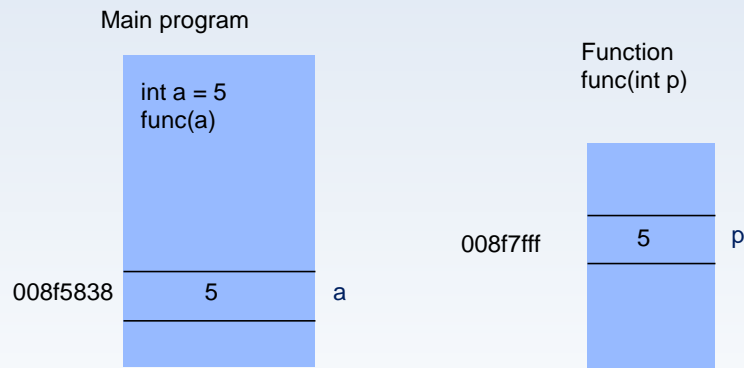
Pass-by-Value vs. Pass-by-Reference

- When an argument is passed **pass-by-value**, a copy of the argument's value is made and passed to the called function.
- With **pass-by-reference**, the addresses of the parameters are passed to the function. Thus, the function is given direct access to these parameters.

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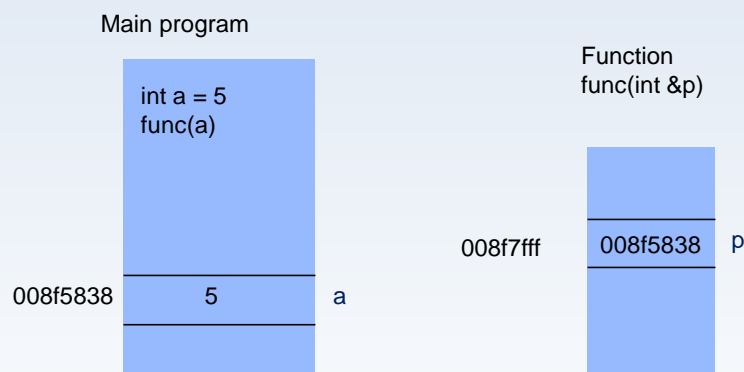
Pass-by-Value



When $p = 7$ is executed in the function, the value of p changes, but the value of a does not

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Pass-by-Reference



When $p = 7$ is executed in the function, the value in address $\&p$ (that is, a) changes.

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Arrays As Arguments

- When an array name is passed to a function, what is passed is the address of the first element of the array.
- Within the called function, this argument is a local variable, and so an array name parameter is a pointer, that is, a variable containing an address.
- **We can use this information as a pointer.**

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Example

```
// return length of string s
int strlen(char *s){
    int n = 0;
    for (n = 0; *s != '\0'; s++)
        n++;
    return n;
}
```

```
int main( )
{
    char a[10] = "array";
    int k;
    char *ptr = a;
    k = strlen("hello world");
    k = strlen(a);
    k = strlen(ptr);
    return 0;
}
```

example0.cpp

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Example

All strings end with the null ('\\0') character. This value corresponds to "false".

```
int strlen(char *s){
    int n = 0;
    while (*s){
        s++;
        n++;
    }
    return n;
}

int main( )
{
    char a[10] = "array";
    int k;
    char *ptr = a;
    k = strlen("hello world");
    k = strlen(a);
    k = strlen(ptr);
    return 0;
}
```

example0.cpp

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Arrays as Arguments

- When an array name is passed to a function, the function can use this information as either an array or a pointer.
- It is also possible to pass part of an array to a function, by passing a pointer to the beginning of the subarray.

`f(&a[2]);`

`f(a + 2);`

Both pass to the function `f` the address of the subarray beginning with the 3. element of array `a`

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Example

```
int strlen(char *s){
    int n = 0;
    for (n = 0; *s != '\0'; s++)
        n++; for (n=0; s[n] != '\0'; n++);
    return n;
}

int main( )
{
    char a[10] = "array";
    int k;
    char *ptr = a;
    k = strlen("hello world");
    k = strlen(&a[2]);
    k = strlen(ptr);
    return 0;
}
```

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Pointer to a Pointer as an Argument

- If we want to change the value of an argument, we pass the address of the argument to the function.
- Similarly, if we want to change the value of a pointer, we pass the address of the pointer to the function (that is, we must pass a pointer to a pointer.)

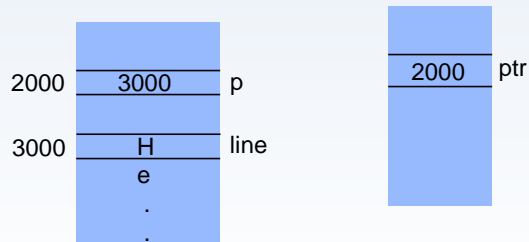
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Pointer to a Pointer as an Argument

```
void f(char **ptr){
    (*ptr)++;
}
```

```
int main( )
{
    char line[20] = "Hello world";
    char *p = line;
    f(&p);
    return 0;
}
```



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Dynamic Memory

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Dynamic Memory Allocation

- At execution time, a program can obtain and use new memory space. Memory space obtained at execution time can be returned to the system when it is no longer needed.
- This ability is known as **dynamic memory allocation**.
- The limit on the size of the memory space that can be allocated is determined by how much the operating system allows. (You will learn about memory management in operating systems in courses to come.)
- In C, functions **malloc** and **free** are essential to manipulating dynamic memory space.
- In C++, the essential functions are the **new** and **delete** operators.
- In this course, we will use **new** and **delete**.

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Pointers and Dynamic Memory Allocation

- It is necessary to use pointers to dynamically request memory space from the system.
- Since the program is compiled and running at that moment, it is not possible to give a symbolic name to the memory space to be allocated.

```
int integer1;
int *dnumber;
```

- **integer1** is a symbolic name and the name of an integer. This name can be used where the variable is defined (in scope).
- **dnumber** is a pointer. It cannot be used yet because it does not point to any memory location. Pointers can only be used if they are pointing to a meaningful memory slot.
- To dynamically allocate memory, there has to be a pointer that can be used.

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new Operator

```
dnumber = new int;
```

- This expression allocates memory space from the system for data of type `int` and assigns the address of this space to the `dnumber` pointer.
- The `new` operator both allocates memory space that is large enough to accommodate a variable of the right type and returns a pointer of a suitable type.
- Compared to the usage of `malloc`, this obviously provides a great convenience. The need for the `sizeof` call and the conversion of the returned "generic" pointer type is eliminated.
- If memory cannot be allocated for whatever reason, `new` returns `NULL`.
- Now, the `dnumber` pointer is pointing to a real location. This dynamic memory space can be accessed using this pointer.

```
*dnumber = 5;
```

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delete Operator

- Dynamically allocated memory space should be returned to the system when it is no longer needed.
- Memory is returned using the expression

```
delete dnumber;
```

Note!

1. If new memory has not been allocated for a pointer that had the memory it was previously pointing to returned to the system, using `delete` again on this pointer may lead to unexpected errors.
2. `delete` can **only** be applied to memory space that has been **allocated with new**.
3. `delete` cannot be applied to pointers pointing to nondynamic variables. These memory slots cannot be returned.

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Dynamic Creation of Arrays

- Dynamic memory may be allocated for the whole array at once.

```
float *darray;
darray = new float[100];
```

- Here, an array large enough to hold 100 real variables has been dynamically created. The start address of the array has been assigned to the `darray` pointer.
- After the above assignment, `darray` can be used to access array elements.
- To return the array to the system:


```
delete [] darray;
```
- Note:** When deallocating the array, we should not forget to use `[]`.

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Discussion

- What happens if dynamically allocated memory slots are not returned?
- Try it out: What is the largest memory space that can be allocated at a time?

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Abstract Data Types

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Abstract Data Types - ADTs

- Integers, real numbers, and Booleans are built-in data types.
- Similarly, we could define more complex abstract data types such as the list, set, stack, and queue.
- Certain operations that can be performed are defined on every built-in data type.
 - Integer addition
 - Real number multiplication
 - Boolean "or" operation
- Likewise, abstract data types are incomplete without the operations that can be performed on them.

Example: On the set structure,

- We could define operations such as union, intersection, complement, and set size.

- **Basic idea:**

- The implementation of these operations is written once in the program.
- Any other part of the program that needs to perform an operation on the ADT can do so by calling the appropriate function.
- If for some reason, implementation details need to be changed, it should be easy to do so by merely changing the functions that perform the ADT operations, and these changes should not affect the programs using this data type. This property is known as **transparency**.
- Which operations (functions) will be defined for an ADT is a design choice, and it is determined by the programmer depending on the need.
- How an ADT will be implemented (that is, how it will be designed and programmed) may vary from programmer to programmer. These design details and differences do not change the outside appearance of the ADT (as viewed by the programs that use it).

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C++ and struct

- In C++, the structure provides a natural capsule for defining an abstract data type.
- Thus, the data type and the functions that define the operations to be performed on this type are located in the same capsule and logically related.

C	C++
<pre>typedef struct DataType{ int a[10]; int elementnumber; } NewArrayType; int CountElmt(NewArrayType *d) { return d->elementnumber; }</pre>	<pre>struct NewArrayType{ int a[10]; int elementnumber; int CountElmt(); }; int NewArrayType::CountElmt() { return elementnumber; }</pre>

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struct

- Structures cannot contain another structure of the same type. They can only contain a reference (pointer) of the same type.

```
struct NewArrayType{
    int a[10];
    int elementnumber;
    NewArrayType *y;
    int CountElmt();
};
```

- Defining a structure does not reserve any space in memory. It only creates a new data type. However, when a structure variable (variable of the type the structure defines) is declared, memory is allocated for this variable.

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struct

The following operations can be performed on structure variables:

- Assignment operation =
- Address operator &
- Member access operators . and ->
- sizeof operator

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struct

- The members of a structure do not have to be located consecutively in memory.
- Passing structures to functions:
The whole structure or its members may be passed to the function. Structures are always passed pass-by-value.
- To pass a structure to a function by reference, we have to pass its reference.
- **Note:** An array that is a member of the structure also gets passed to the function by value.
- When the assignment operator (=) is used between structures, all members are copied.

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struct (advanced topics)

- By defining nested structures, more general-purpose (easier to update based on the data type it holds) programs can be written.
- This situation is a choice completely dependent on the design.
- Example:

```
struct node{
    char firstname[20];
    char lastname[20];
    node *next;
};
void add(char *firstname, char *lastname){
    node *newnode = new node;
    strcpy(newnode->firstname, firstname);
    strcpy(newnode->lastname, lastname);
    . . .};
add("ahmet", "cetin");
```

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Example

```
struct nodedata{
    char firstname[20];
    char lastname[20];
};
struct node{
    nodedata data;
    node *next;
};
void add(nodedata d){
    node *newnode = new node;
    newnode->data = d;
    . . .};
nodedata d = {"ahmet", "cetin"};
add(d);
```

In structures, since the "=" operation copies the whole content, the data part will be completely copied independent of content. Thus, it will not be necessary to update the code by performing different copying operations for different types. The node "newnode" is stored in a different location in memory.

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Example

- Note: What if the node data is as follows?

```
struct nodedata{
    char firstname[20];
    char lastname[20];
};
```



```
struct nodedata{
    char *firstname;
    char *lastname;
};
```

`newnode->data = d;` Which operation will be performed?

The result of the operation in the first structure and the second structure will be different. In the first structure, array contents are copied to a new location, while in the second structure, only pointer values are copied. The values of `firstname` and `lastname` pointers will be copied. In other words, the address values they hold will be copied. In this case, the pointers in the `data` part of the "newnode" structure and pointers of the `d` structure will point to the same location in memory.

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```
struct nodedata{
    char firstname[20];
    char lastname[20];
};
```



```
struct nodedata{
    char *firstname;
    char *lastname;
};
```

Name	Value
v	{...}
name	0x0012fee4 "ahmet"
lastname	0x0012fef8 "cetin"
newnode	0x00441ba0
data	{...}
name	0x00441ba0 "ahmet"
lastname	0x00441bb4 "cetin"
next	0xcdcdcdcd

Name	Value
v	{...}
name	0x0042e024 "ahmet"
lastname	0x0042e01c "cetin"
newnode	0x00441bc0
data	{...}
name	0x0042e024 "ahmet"
lastname	0x0042e01c "cetin"
next	0xcdcdcdcd

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To do: In recitation

- Solution to Homework 2
- Function calls
- Parameter passing
- Where in a program the variable may be used (scope)

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Homework

In the PhoneBook example, phonerecords were defined as constant-size arrays. Realize the necessary operations (in code) for defining dynamic sizes for these arrays.

Homework

The phonebook example was solved using an array. In this homework, you should use a dynamic array instead of a static array. In this structure, this is what you need to do:

First, inside the phonebook structure, you should define a variable `size=5`. Within `Book.create`, an array of this size will be dynamically allocated. Then, every addition operation will check to see if the current index has reached `size`. If the array is full (that is, the index has reached `size`), then a function called `increase size` will be called. This function will allocate a dynamic array of `size*2` from the memory. We will call this new array. This function will first copy the elements in the array to the beginning of the new array using a loop. Then, the old array will be returned to the system. The array will be assigned to the new array. And the new size will be defined as two times as big.