Elementary Data Structures

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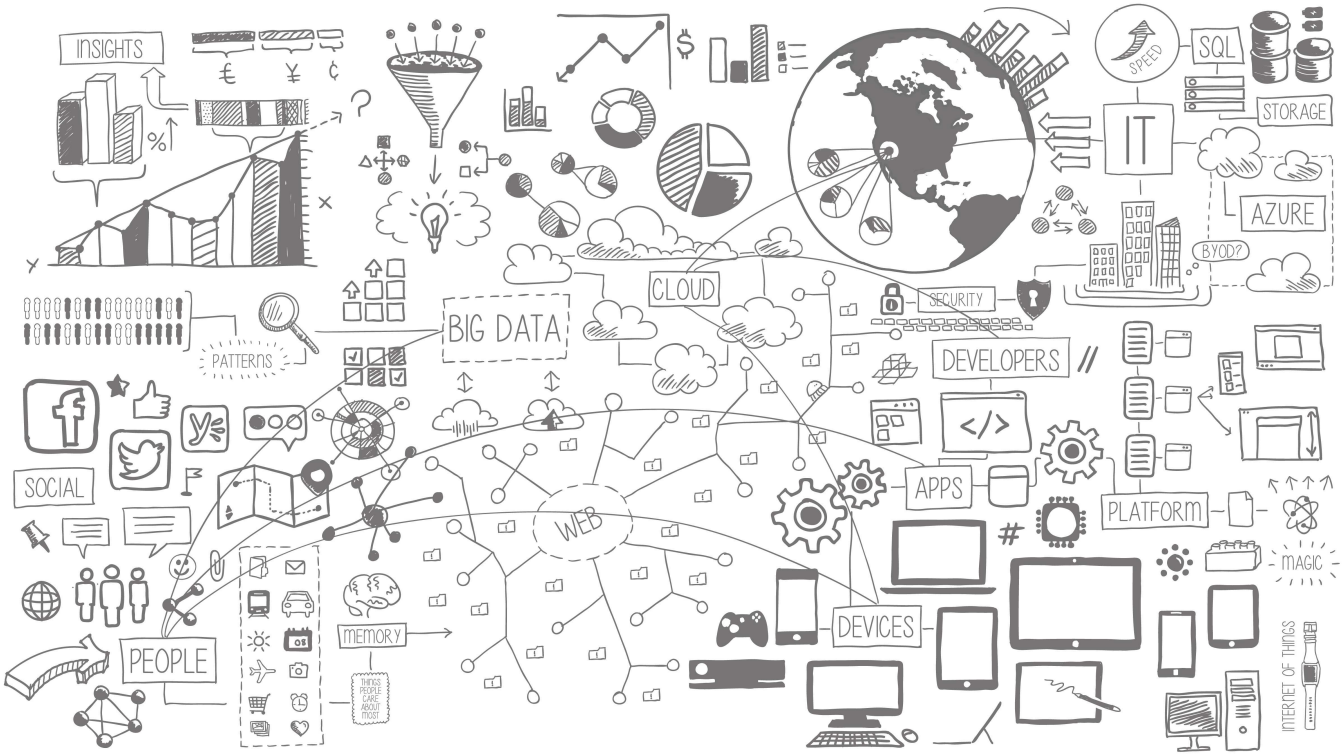
Today Objectives

- Introduce the fundamental definitions in C/C++.
- Review elementary data types in programming such as array, pointer, structure, enumeration, etc.
- Study the C/C++ examples.

Data

Data refers to the fact that some existing information or knowledge. Data is a set of values of qualitative or quantitative **variables**.



Data

Everything can be considered as data:

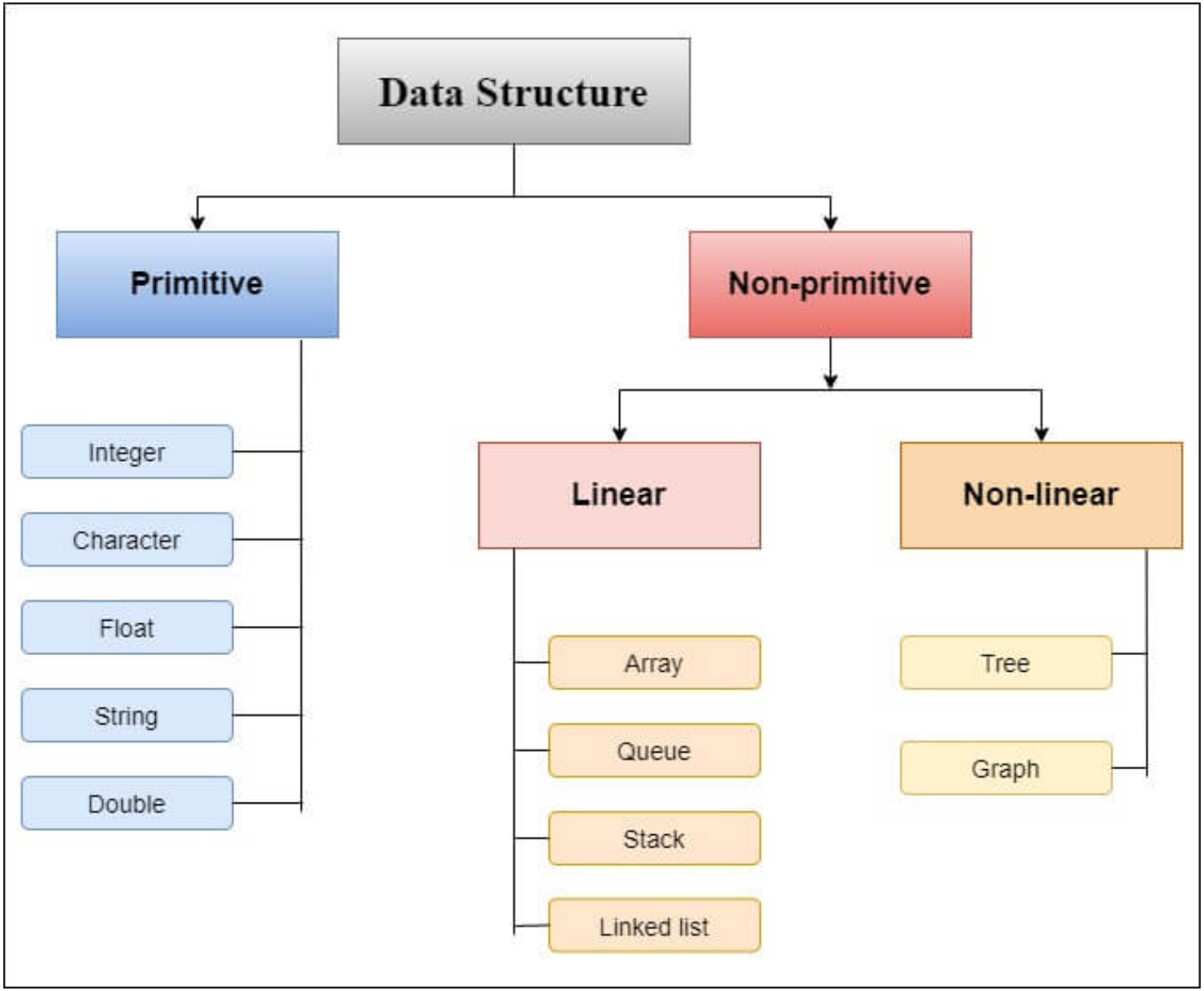
- name, age, address of a person
- number, series of number
- pixels or images in RGB color model or grayscale
- linear functions, polynomial functions, exponential functions
- trees, graphs, maps, documents

Data

Benchmark datasets

- UCI Dataset Repository: text, number (`https://archive.ics.uci.edu/ml/index.php`);
- Amazon customer review: text, number (`https://jmcauley.ucsd.edu/data/amazon/`);
- COCO16, MNIST: images (`https://cocodataset.org/#home`);
- SNAP dataset collection: graph (`https://snap.stanford.edu/data/`);
- and even more...

Data Structure



Data Structure

Applications

- List of items in the cart when you visit an online shop
- List of possible actions (undo/redo) in a word editor
- Bitmap (array 2D) to store image pixels
- Graph to represent a group of persons and their relationship (Graph Theory, Graph Mining)
- Tree to arrange and index data like web pages, images, etc.

Definitions

Variables

Being used to store data, variables are simply names used to refer to some location in memory, a location that we can use to write, retrieve, and manipulate throughout the program.

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Variable declaration

Variable declaration shows a specific type, which determines the size used in the memory; the range of values that can be stored within that memory; and the set of operations that can be applied to the variable.

Variables

Variable name is an identifier for that variable call-by-name; reference-by-name. The name can be composed of letters, digits, and the underscore character. Upper and lowercase letters are distinct.

```
1 <Type> <Variable>;
2 float F;
3 // declaration of a real number F
4 int id;
5 // declaration of an integer as an id
6 char *address;
7 // declaration of a string of characters
```

Variables

A variable MUST be initialized with a value before it is used.

Code C/C++

```
1  int student_number=1254;
2  double scholarship=1132.50;
3  unsigned char gender=1;
4  string *home_address="Hanoi";
5  char   class_type='A';
```

Integer Types

There are a few ways to declare an integer:

```
1 char                short int          unsigned short int
2 signed char         int                unsigned int
3 unsigned char       long int           unsigned long int
```

Type	Size	Description
char	8 bits	an integer type $[-127; 127]$
(signed) int	32 bits	the most natural size of integer for a computer $[-2^{31} - 1; 2^{31} + 1]$
unsigned	32 bits	non-negative integer number
short	16 bits	a half of normal integer size
long	64 bits	a double of normal integer size

Real Types

Represent real values, such as 3.14 or 0.01, with different levels of precision, depending on which of the three floating-point types is used.

Type	Size	Description
float	32 bits	a single-precision floating point value
double	64 bits	a double-precision floating point value
long double	$\geq$ 64 bits	often more precise than double precision

Character Type

Besides the use as an integer, char also can be declared for a character. The value is determined at the character code in the ASCII table.

```
1 char ch = 65;     // an integer
2 char ch = 'A';    // a character
```

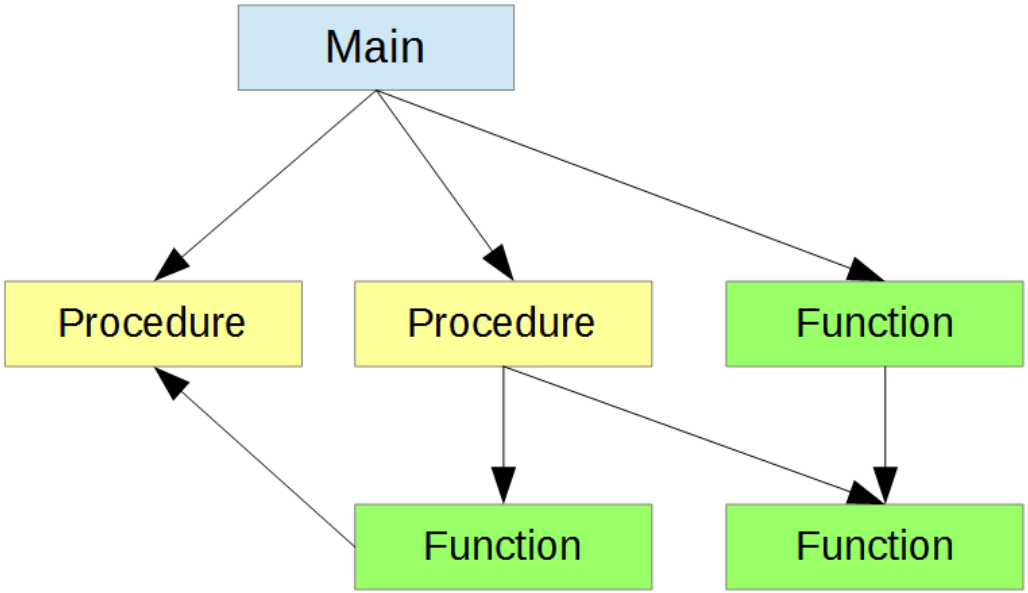
Examples

```
1  int a, b;  float c;  char d = 'A';
2  b = 1;
3  a = b + 4.5;
4  c = a / 4;
5  d = c + d;
6  printf("%d, %d, %f, %d", a, b, c, d);
```

```
1  int a, b;  float c;  char d = 'A';
2  b = 1;
3  a = b + 4.5;
4  c = a / 4.0;
5  d = c + d;
6  printf("%d, %d, %f, %c", a, b, c, d);
```

Computer program

A computer program is a collection of instructions that performs a specific task when executed by a computer. A program always consists of a main including many functions and procedures.



Function

Function

A named section of a computer program that performs a specific task and returns a value.

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```
1  int sum(int n){
2      int s = 0;
3      for (int i = 1;i<=n;i++)
4          s += i;
5      return s;
6  }
```

Function

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2      int s = 0;
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4          s += i;
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6  }
```

Attention

return has to be used to return the value and complete the function.

Function

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A function can be called or used in other functions.

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```
1  int doublesum(int n){
2      int sum2 = sum(n) + sum(n);
3      return sum2;
4  }
5  int main(){
6      int n = 10;
7      int sum1 = sum(10);
8      int sum2 = doublesum(10*sum(n));
9      return 0;
10 }
```

Void

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Void means nothing to be used in C, C++

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```
1  int myFunction(void) {
2      return 10; // function parameters are absent
3  }
4  void myFunction(){
5     statement;     // the return value is absent
6  }
```

Void

Void

Void means nothing to be used in C, C++

```
1  int myFunction(void) {
2      return 10; // function parameters are absent
3  }
4  void myFunction(){
5     statement;     // the return value is absent
6  }
```

Attention

return in a void function is unnecessary; however, it can be used to exit void functions.

Void

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Void functions can be called and used like normal functions.

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```
1  void myPrint() {
2      printf("Hello World!");
3      return;
4  }
5  void myPrint2(int n){
6      printf("Number is %d", n);
7  }
8  int main(){
9     myPrint();
10    myPrint2(100);
11    return 0;
12 }
```

Global variable vs local variable

Global variable

A global variable is a variable that it is visible (hence accessible) throughout the program. Its value can be changed anywhere in the code.

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Local variable

A local variable is a variable that is either a variable declared within the function or is an argument passed to a function. This type of variable can only be used within a function; after the execution, local variables are removed from the computer memory.

Global variable vs local variable

Code C/C++

```
1  int main(){
2      int result = sum(10); // local variable
3  }
4  int sum(int n){
5      int s = 0; // local variable
6      for (int i = 1;i<=n;i++){
7          s += i;
8      }
9      return s;
10 }
```

Global variable vs local variable

Code C/C++

```
1  #include <stdio.h>
2  int add_numbers( void );
3  int value1, value2, value3;
4  int add_numbers( void ){
5      int result = value1 + value2 + value3;
6      return result;
7  }
8  int main(){
9      int result;
10     value1 = 10; value2 = 20; value3 = 30;
11     result = add_numbers();
12     printf("The sum of %d + %d + %d is %d\n",
13     value1, value2, value3, result);
14     return 0;
15   }
```

Arrays

Definition

- An array is a predefined-size sequential collection of N elements of the same type.
- The objects are called elements of the array, and are indexed by their order in the sequence.
- The element indices are from 0 to $N - 1$.

```
1 <type> <name>[<number of elements>];
2 int age[100]; /* declaration of an array
3 consisted of 100 integer variables */
4 float series[50]; /* declaration of an array
5 consisted of 50 float variables */
```

Note: this array initialization is called "static"; the size must be defined during the variable declaration and cannot be extended.

Arrays

To access an element in an array, an index is available for use such as $a[0], b[1], a[i], b[i+j]$ with $i, j \in \mathbb{N}$. A basic loop permits to process every element in the array.

```
1  for (i = 0; i < n; i++){
2     <processing the ith element of the array>;
3   }
```

Multi-Dimensional Arrays

The simplest form of the multi-dimensional array is the two-dimensional array (a table or a matrix). It can be extended to more general multi-dimensional cases. It's preferable to avoid arrays of dimensions more than 3.

```
1 <type> <name> [<nb>][<nb>]...;
2 int a[3][4][5];
3 double b[10][10];
4 char str[17][5];
```

Multi-Dimensional Arrays

The table indicates the structure of an two dimensional array with an element denoted by $a[i][j]$ where i is the i^{th} row and j is the j^{th} column.

	Column 0	Column 1	Column 2	Column 3
Row 0	a[0][0]	a[0][1]	a[0][2]	a[0][3]
Row 1	a[1][0]	a[1][1]	a[1][2]	a[1][3]
Row 2	a[2][0]	a[2][1]	a[2][2]	a[2][3]

Multi-dimensional arrays may be initialized by specifying bracketed values for each row.

```
1  int a[2][3]={{1,5,8},{2,4,7}};
2  for (int i = 0; i < 2; i++)
3      for (int j = 0; i < 3; j++)
4          statement;
```

Pointers

Definition

A pointer is a variable whose value is the address of another variable, i.e., the direct address of the memory location. Like any variable or constant, a pointer must be declared before its use to store any variable address.

```
1  int count;
2  int *countPtr = &count;
3  int *undecided = NULL;
4  int &countAlias = count;    // In C++
```

Pointers

Definition

Reference of a pointer must be initialized when declared. Pointer could be initialized with NULL.

- & or ampersand indicate a reference of a variable.
- * allows getting the value of the variables being pointed by pointers.

References

Creating references

- Consider a variable name as a label attached to the variable's location in memory.
- A reference is a second label attached to that memory location.

Example

We can declare reference variables for i as follows.

```
1  int      i = 17;
2  int &r = i;
```

Read the & in these declarations as reference: "r is an integer reference initialized to i".

References

Example

```
1  int i = 17;
2  int &r = i;
3  int d = i;
4  i = i+3;
```

What are the final values for r and d?

References vs Pointers

References are often confused with pointers, but

- Compilers generate a reference to each variable (after variable declaration).
- There are no NULL references. A reference is connected to a legitimate piece of memory.
- Once a reference is initialized to an object; it cannot be changed to refer to another object. Pointers can be pointed to another object at any time.
- A reference must be initialized when it is created. Pointers can be initialized at any time.

Pass By Value

Note

The variables in the formal parameter list are always local variables of a function

- With Pass By Value, function parameters receive copies of the data sent in.
- The original variables passed into a function from another function are not affected by the function call.

Pass By Value

Example

```
1  #include <iostream>
2  using namespace std;
3  void twice1(int x){
4    x = x*2;                    // LOCAL value of x will change
5  }
6  int twice2(int x){
7    return x*2;    // return value of x gets changed
8  }
9  int main () {
10    int     i = 10;
11    twice1(i);
12    printf(''Returned value of the first function: %d'', i);
13    i = twice2(i);
14    printf(''Returned value of the second function: %d'', i);
15    return 0;
16 }
```

What is the result?

Pass By Value

Example

```
1  #include <iostream>
2  using namespace std;
3  int twice(int x, int y){
4    x = x*2;  // LOCAL value of x will change
5    y = y*2;  // LOCAL value of y will change
6    return x;
7  }
8  int main () {
9     int     a = 10;
10    int     b = 5;
11    b = twice(a,b);
12    printf(``Values of a = %d, and b = %d'', a, b);
13    return 0;
14 }
```

What is the result?

Pass By Reference

- The parameters are still local to the function, but they are reference variables.
- The variables passed into a function DO get changed by the function call.

Example

```
1  void twice(int &x, int &y){
2    x = x*2;  // these WILL affect the original arguments
3    y = y*2;  // these WILL affect the original arguments
4  }
```

Pass By Reference

Example

```
1  #include <iostream>
2  using namespace std;
3  void twice(int &x, int &y){
4    x = x*2;  // these WILL affect the original arguments
5    y = y*2;  // these WILL affect the original arguments
6  }
7  int main () {
8     int     a = 10;
9     int     b = 5;
10    twice(a,b);
11    printf(``Values of a = %d, and b = %d'', a, b);
12    return 0;
13 }
```

What is the result?

Pass By Reference

Note

When a function expects strict reference types in the parameter list, a value (i.e., a variable or storage location) must be passed in.

Example

```
1  void twice(int &x, int &y){
2    x = x*2;  // these WILL affect the original arguments
3    y = y*2;  // these WILL affect the original arguments
4  }
5  int main(){
6    int a = 6, b = 10;
7    twice(a, b);    // it is legal
8    twice(4, b);    // it is NOT legal
9    twice(a, b-5);    // it is NOT legal
10 }
```

Value vs. Reference

Pass By Value

- The local parameters are copies of the original arguments passed in.
- Changes in the function to these variables do not affect originals.

Pass By Reference

- The local parameters are references to the storage locations of the original arguments passed in.
- Changes to these variables in the function will affect the originals.
- No copy is made, so the overhead of copying (time, storage) is saved.

Arrays vs Pointers

- A variable declared as an array of some type acts as a pointer to that type.
- A pointer can be indexed to access an array.

```
1  int a[10], *intPtr;
2  intPtr = a; //intPtr pointing to a[0]
3  *(intPtr+5) = 4; //a[5]=4
4  intPtr = &a[7]; //intPtr pointing to the 7th element
5  intPtr++; //intPtr pointing to the 8th element
```

Arrays vs Pointers

Pointers can also be assigned to reference "dynamically" allocated memory. The **malloc()** and **calloc()** functions are often used to do this.

```
1  int *intPtr;
2  int size;
3  scanf("%d", &size);
4  intPtr = (int *)malloc(sizeof(int)*(size+10));
5  *(intPtr + 3) = 5;
6  intPtr[3] = 5;
7  free(intPtr);
```

Arrays vs Pointers

An array of pointers is an indexed set of variables, where the variables are pointers.

```
1  int *Ptr[5];
2  char *Ptr = "Hello, World";
3  char *Ptr[4]={"Spring","Summer","Autumn","Winter"};
```

Strings

String

String is a one-dimensional array of characters that is terminated by a NULL character '\0'. Built-in functions for C-string is in <string.h>.

```
1  char str1[5]; //maximal 4 characters
2  char str3[]="HANOI";
3  char *str4;
4  char *str4= (char *)calloc(6,sizeof(char));
5  char *str4="HANOI";
```

Strings

- One possible way to read in a string is by using **scanf()**. This function finishes reading when it reaches a space, or the string would get cut off.
- The function **gets()** can overcome this issue.

```
1 scanf(``%s``,str);
2 // finish when it reaches space or enter
3
4 gets(str)
5 /* finish when it reaches EOL or EOF replace
6  it with 0  they do not do the bound checking
7  of the string! */
```

Structures

Structure is user defined data type available in C programming, which allows to combine one or more variables, possibly of different types, grouped together under a single name for convenient handling.

```
1 struct [structure tag]{
2     member definition;
3     member definition;
4     ...
5     member definition;
6 } [structure name];
```

Structures

```
1  typedef struct Student{
2      int age;
3      char name[50];
4      unsigned char gender;
5  } ;
6  struct Student s1, s2;
```

```
1  struct StudentUSTH{
2      int age;
3      char name[50];
4      unsigned char gender;
5  };
6  typedef struct StudentUSTH STH;
7  STH s1, s2;
```

Structures

To access and process structure fields, dot '.' operator can be used

```
1  s1.age = 20;
2  s2.name = 'Nguyen Van An';
```

Or using this symbol $'->'$ when it involves in pointers

```
1  s1->age = 20;
2  s2->name = 'Nguyen Van An';
```

Structures and Pointers

Pointer can be used for a single structure variable, but it is mostly used with array of structure variables.

```
1  #include <stdio.h>
2  struct Book{
3    char name[1000];
4    int price;
5  };
6  int main(){
7    struct Book a;        // Single structure variable
8    struct Book* ptr;     // Pointer of Structure type
9    ptr = &a;
10   struct Book b[10];    // Array of structure variables
11   struct Book* p;       // Pointer of Structure type
12   p = &b;
13 }
```

Enumeration

Enumerated types are types that are defined with finite number of values, known as enumerators, as possible values. The key word for an enumerated type is enum. Here is the syntax:

```
enum <type_name> {
    enum_val1,
    enum_val2,
    enum_val3,
    ...};
```

```
enum Season {Spring, Fall, Summer, Winter};
Season s1, s2;
s1 = Summer;
s2 = Fall;
if (s1 == Summer)
    printf(''Summer is comming'');
```