Data types, arrays, pointer, memory storage classes, function call

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Lecture 03

B3B36PRG – C Programming Language

Overview of the Lecture

Part I

Data Types

Basic Data Types

- Basic (built-in) types are numeric integer and floating types

  *Logical data type has been introduced in **C99***
- C data type keywords are
  - Integer types: `int`, `long`, `short`, and `char`
    Range "modifiers": `signed`, `unsigned`
  - Floating types: `float`, `double`
    May also be used as `long double`
  - Character type: `char`

    Can be also used as the integer type
  - Data type with empty set of possible values: `void`
  - Logical data type: `_Bool`
- Size of the memory representation depends on the system, compiler, etc.
  - The actual size of the data type can be determined by the `sizeof` operator
- New data type can be introduced by the `typedef` keyword

Basic Numeric Types

- Integer Types – `int`, `long`, `short`, `char`

  `char` – integer number in the range of single byte or character

  - Size of the allocated memory by numeric variable depends on the computer architecture and/or compiler

    Type `int` usually has 4 bytes even on 64-bits systems

  - The size of the memory representation can be find out by the operator **sizeof()** with one argument name of the type or variable.

```
int i;
printf("%lu\n", sizeof(int));
printf("ui size: %lu\n", sizeof(i));
```

lec03/types.c

- Floating types – `float`, `double`

  Depends on the implementation, usually according to the IEEE Standard 754 (1985) (or as IEC 60559)

  - **float** – 32-bit IEEE 754
  - **double** – 64-bit IEEE 754

http://www.tutorialspoint.com/cprogramming/c_data_types.htm

Integer Data Types

- Size of the integer data types are not defined by the C norm but by the implementation

  They can differ by the implementation, especially for 16-bits vs 64-bits computational environments.

- The C norm defines that for the range of the types, it holds that
  - `short` $\leq$ `int` $\leq$ `long`
  - `unsigned short` $\leq$ `unsigned` $\leq$ `unsigned long`
- The fundamental data type `int` has usually 4 bytes representation on 32-bit and 64-bit architectures

  Notice, on 64-bit architecture, a pointer is 8 bytes long vs int

- Data type size the minimal and maximal value

Type	Min value	Max value
`short`	-32,768	32,767
`int`	-2,147,483,648	2,147,483,647
`unsigned int`	0	4,294,967,295

Signed and Unsigned Integer Types

- In addition to the number of bytes representing integer types, we can further distinguish
  - **signed** (default) and
  - **unsigned** data types

    A variable of unsigned type cannot represent negative number

  - Example (1 byte):

    `unsigned char`: values from 0 to 255

    `signed char`: values from -128 to 127

```
unsigned char uc = 127;
char su = 127;

printf("The value of uc=%i and su=%i\n", uc, su);
uc = uc + 2;
su = su + 2;
printf("The value of uc=%i and su=%i\n", uc, su);
```

lec03/signed_unsigned_char.c

Integer Data Types with Defined Size

- A particular size of the integer data types can be specified, e.g., by the data types defined in the header file `<stdint.h>`

  IEEE Std 1003.1-2001

`int8_t`	`uint8_t`
`int16_t`	`uint16_t`
`int32_t`	`uint32_t`

lec03/inttypes.c

http://pubs.opengroup.org/onlinepubs/009695399/basedefs/stdint.h.html

Floating Types

- C provides three floating types
  - `float` – Single-precision floating-point
    Suitable for local computations with one decimal point
  - `double` – Double-precision floating-point *Usually fine for most of the programs*
  - `long double` – Extended–precision floating-point *Rarely used*
- C does not define the precision, but it is mostly IEEE 754 *ISO/IEC/IEEE 60559:2011*
  - **double** – 64 bits (8 bytes) with sign, exponent, and mantissa
    - s – 1 bit sign (+ or −)
    - **Exponent** – 11 bits, i.e., 2048 numbers
    - **Mantissa** – 52 bits ≈ 4.5 quadrillions numbers *4 503 599 627 370 496*
  - A rational number x is stored according to

$$x = (-1)^s \mathbf{Mantisa} \cdot 2^{\mathbf{Exponent}-\mathbf{Bias}}$$

  - **Bias** allows to store exponent always as positive number
    It can be further tuned, e.g., Bias $= 2^{eb-1} - 1$, where eb is the number bits of the exponent.

Character – char

- A single character (letter) is of the `char` type
- It represents an integer number (byte)
  Character encoding (graphics symbols), e.g., ASCII – American Standard Code for Information Interchange.
- The value of `char` can be written as *constant*, e.g., `'a'`.

```
char c = 'a';

printf("The value is %i or as char '%c'\n", c, c);
```

lec03/char.c

```
clang char.c && ./a.out
The value is 97 or as char 'a'
```

- There are defined several control characters for output devices
  *The so-called **escape sequences***
  - \t – tabular, \n – newline,
  - \a – beep, \b – backspace, \r – carriage return,
  - \f – form feed, \v – vertical space

Boolean type – _Bool

- In **C99**, the logical data type `_Bool` has been introduced

```
_Bool logic_variable;
```

- The value *true* is any value of the type `int` different from 0
- In the header file `stdbool.h`, values of `true` and `false` are defined together with the type `bool`
  Using preprocessor

```
#define false 0
#define true  1

#define bool  _Bool
```

- In the former (ANSI) C, an explicit data type for logical values is not defined
  - A similar definition as in `<stdbool.h>` can be used

```
#define FALSE 0
#define TRUE 1
```


Type Conversions – Cast

- Type conversion transforms value of some type to the value of different type
- Type conversion can be
  - **Implicit** – automatically, e.g., by the compiler for assignment
  - **Explicit** – must be prescribed using the **cast operator**
- Type conversion of the **int** type to the **double** type is implicit
  Value of the `int` type can be used in the expression, where a value of the `double` type is expected. The `int` value is automatically converted to the `double` value.

Exampl

```
double x;
int i = 1;

x = i; // the int value 1 is automatically converted
       // to the value 1.0 of the double type
```

- Implicit type conversion is safe

Explicit Type Conversion

- Tranformation of values of the **double** type to the **int** type has to be explicitely prescribed by the **cast operator**
- The franctional part is truncated

Příklad

```
double x = 1.2; // declaration of the double variable
int i;          // declaration of the int variable
int i = (int)x; // value 1.2 of the double type is
                // truncated to 1 of the int type
```

- Explicit type conversion can be potentially dangerous

Examples

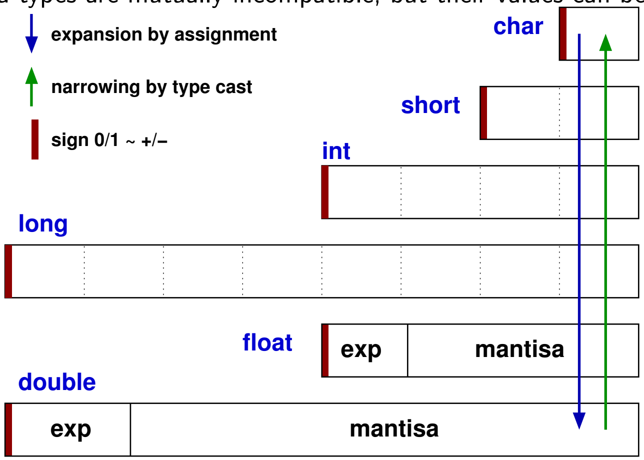
```
double d = 1e30;
int i = (int)d;

// i is -2147483648
// which is ~ -2e9 vs 1e30
```

```
long l = 5000000000L;
int i = (int)l;

// i is 705032704
// (truncated to 4 bytes)
```

lec03/demo-type_conversion.c

Type Cast of Numeric Types

- The basic data types are mutually incompatible, but their values can be transformed by type cast

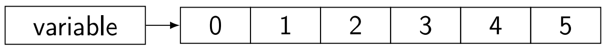


Array

- A data structure to store **several data values of the same type**

  Values are stored in a continues block of memory
- Each element has identical size, and thus its relative address from the beginning of the array is uniquely defined
  - Elements can be addressed by order of the element in the array

"address"=size_of_element * index_of_element_in_the_array



- The variable of the **array type** represents the address of the memory, where the particular values are stored

  Address = 1st_element_address + size_of_the_type * index_of_the_element
- The memory is allocated by the definition of the array variable
  - The array always has a particular size, i.e., defined by the number of the elements or automatically allocated by the compiler
- Once the array is defined, its size cannot be changed!

Array Definition

- Definition consists of the type (of the array elements), name of the variable, and size (the number of elements) in the [] brackets

  type variable [];
- **[]** is also the array subscripting operator

  array_variable [index]

Example of array of `int` elements

```
int array[10];
```

I.e., 10 × `sizeof(int)`

```
printf("Size of array %lu\n", sizeof(array));
printf("Item %i of the array is %i\n", 4, array[4]);
```

```
Size of array 40
Item 4 of the array is -5728
```

Values of individual elements are not initialized!

C does not check validity of the array index during the program run time!

Arrays – Example

- Definition of 1D and two-dimensional arrays

```
/* 1D array with elements of the char type */
char simple_array[10];
```

```
/* 2D array with elements of the int type */
int two_dimensional_array[2][2];
```

- Accessing elements of the array

```
m[1][2] = 2*1;
```

- Example of the array definition and accessing its elements

```
#include <stdio.h>

int main(void)
{
   int array[5];

   printf("Size of array: %lu\n", sizeof(array));
   for (int i = 0; i < 5; ++i) {
      printf("Item[%i] = %i\n", i, array[i]);
   }
   return 0;
}
```

```
Size of array: 20
Item[0] = 1
Item[1] = 0
Item[2] = 740314624
Item[3] = 0
Item[4] = 0
```

lec03/array.c

Array in a Function and as a Function Argument

- Array defined in a function is a local variable

The of the local variable is only within the block (function).

```
void fce(int n)
{
   int array[n];
   // we can use array here
   {
      int array2[n*2];
   } // end of the block destroy local variables
   // here, array2 no longer exists
} // after end of the function, a variable is automatically destroyed
```

  - Array (as any other local variable) is automatically created at the definition, and it is automatically destroyed at the end of the block (function);

    The memory is automatically allocated and released.
  - Local variables are stored at the **stack**, which is usually relatively small
  - Therefore, it may be suitable to allocate a large array dynamically (in the so called **heap** memory) using pointers
- Array can be argument of a function

```
void fce(int array[]);
```

However, the value is passed as **pointer**!

Pointer

- Pointer is a variable which **value is an address** where the value of some type is stored
- Pointer *refers* to the memory location where a value (e.g., of another variable) is stored
- **Pointer is of type** of the data it can refer

  Type is important for the pointer arithmetic
  - Pointer to a value (variable) of primitive types: `char`, `int`, ...
  - "Pointer to an array"; pointer to function; pointer to a pointer
- Pointer can be also without type, i.e., **void** pointer
  - Size of the variable (data) cannot be determined from the void pointer
  - The pointer can point to any address
- Empty address is defined by the symbolic constant **NULL**

  C99 – `int` value 0 can be used as well

Validity of the pointer address is not guaranteed!

Pointers allow to write efficient codes, but they can also be sources of many bugs. Therefore, acquired knowledge of the indirect addressing and memory organization is crucial.

Address and Indirect Operators

- **Address operator – &**
  - It returns the address of the memory location, where the value of the variable is stored

    &variable
- **Indirect operator – ***
  - It returns the **l-value** corresponding to the value at the address stored in the pointer variable ***variable_of_the_pointer_type**
  - It allows to read and write values of the memory location addressed by the value of the pointer, e.g., pointer to the `int` type as `int *p`

```
*p = 10; // write value 10 to the address stored in the p variable
```

```
int a = *p; // read value from the address stored in p
```

- The address can be printed using `"%p"` in the `printf()` function

```
int a = 10;
int *p = &a;

printf("Value of a %i, address of a %p\n", a, &a);
printf("Value of p %p, address of p %p\n", p, &p);
```

```
Value of a 10, address of a 0x7fffffffe95c
Value of p 0x7fffffffe95c, address of p 0x7fffffffe950
```

Pointer – Examples 1/2

```
int i = 10; // variable of the int type
            // &i - adresa of the variable i

int *pi;    // declaration of the pointer to int
            // pi pointer to the value of the int type
            // *pi value of the int type

pi = &i;    // set address of i to pi

int b;      // int variable

b = *pi;    // set content of the addressed reference
            // by the pi pointer to the to the variable b
```


Pointer – Examples 2/2

```
printf("i: %d -- pi: %p\n", i, pi); // 10 0x7fffffffe8fc
printf("&i: %p -- *pi: %d\n", &i, *pi); // 0x7fffffffe8fc 10
printf("*(&)i: %d -- &(*pi): %p\n", *(&i), &(*pi));

printf("i: %d -- *pj: %d\n", i, *pj);   // 10 10
i = 20;
printf("i: %d -- *pj: %d\n", i, *pj);   // 20 20

printf("sizeof(i): %lu\n", sizeof(i));  // 4
printf("sizeof(pi): %lu\n", sizeof(pi));// 8

long l = (long)pi;
printf("0x%lx %p\n", l, pi); /* print l as hex  -- %lx */
// 0x7fffffffe8fc 0x7fffffffe8fc

l = 10;
pi = (int*)l; /* possible but it is nonsense */
printf("l: 0x%lx %p\n", l, pi); // 0xa 0xa
```

lec03/pointers.c

Pointers and Coding Style

- The **pointer type** is denoted by the `*` symbol
- `*` can be attached to the type name or the variable name
- `*` attached to the variable name is preferred to avoid oversight errors

  `char* a, b, c;` — *Only* `a` *is the pointer*

  `char *a, *b, *c;` — *All variables are pointers*
- Pointer to a pointer to a value of `char` type is `char **a;`
- Writting pointer type (without variable): `char*` or `char**`
- Pointer to a value of empty type

  `void *ptr`
- Guaranteed not valid address has the symbolic name `NULL`

  Defined as a preprocessor macro (0 can be used in ***C99****)*
- Variables in C are not automatically initialized, and therefore, pointers can reference any address in the memory
- Thus, it may be suitable to **explicitly** initialize pointers to `0` or `NULL`

  E.g., `int *i = NULL;`

Part II

Functions and Memory Classes

Passing Arguments to Function

- In C, **function argument is passed by its value**
- Arguments are local variables (allocated on the stack), and they are initialized by the values passed to the function

```c
void fce(int a, char *b)
{ /*
a - local variable of the int type (stored on the stack)
b - local variable of the pointer to char type (the value
    is address) the variable b is stored on the stack */
}
```

- Change of the local variable does not change the value of the variable (passed to the function) outside the function
- However, by passing a pointer, we have access to the address of the original variable

We can achieve a similar behaviour as passing by reference.

Passing Arguments – Example

- The variable a is passed by it value
- The variable b "implements calling by reference"

```c
void fce(int a, char* b)
{
   a += 1;
   (*b)++;
}
int a = 10;
char b = 'A';
printf("Before call a: %d b: %c\n", a, b);
fce(a, &b);
printf("After call a: %d b: %c\n", a, b);
```

- Program output

```
Before call a: 10 b: A
After call a: 10 b: B
```

lec03/function_call.c

Passing Arguments to the Program

- We can pass arguments to the `main()` function during program execution

```c
#include <stdio.h>

int main(int argc, char *argv[])
{
   printf("Number of arguments %i\n", argc);
   for (int i = 0; i < argc; ++i) {
      printf("argv[%i] = %s\n", i, argv[i]);
   }
   return argc > 1 ? 0 : 1;
}
```

```
clang demo-arg.c -o arg

./arg one two three

Number of arguments 4
argv[0] = ./arg
argv[1] = one
argv[2] = two
argv[3] = thre
```

lec03/demo-arg.c

- The program return value is passed by `return` in `main()`

```
./arg >/dev/null; echo $?
1

./arg first >/dev/null; echo $?
0
```

- In shell, the program return value is stored in `$?`, which can be by `echo`
- `>/dev/null` redirect the standard output to `/dev/null`

Reminder

Program Interaction using `stdin`, `stdout`, and `stderr`

- The main function `int main(int argc, char *argv[])`
  - We can pass arguments to the program as text strings
  - We can receive return value of the program

    By convention, 0 without error, other values indicate some problem
  - At runtime, we can read from `stdin` and print to `stdout`

    E.g., using `scanf()` *or* `printf()`
  - We can redirect `stdin` and `stdout` from/to a file

    In such a case, the program does not wait for the user input (pressing "Enter")
  - In addition to `stdin` and `stdout`, each (terminal) program has standard error output (`stderr`), which can be also redirected

    `./program <stdin.txt >stdout.txt 2>stderr.txt`
  - Instead of `scanf()` and `printf()` we can use `fscanf()` and `fprintf()`
    - The first argument of the functions is a file, but they behave identically
    - Files `stdin`, `stdout` and `stderr` are defined in `<stdio.h>`

Program Output Redirection – Example

```c
#include <stdio.h>

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

   fprintf(stdout, "Program has been called as %s\n", argv[0]);
   if (argc > 1) {
      fprintf(stdout, "1st argument is %s\n", argv[1]);
   } else {
      fprintf(stdout, "1st argument is not given\n");
      fprintf(stderr, "At least one argument must be given!\n");
      ret = -1;
   }
   return ret;
}
```

lec03/demo-stdout.c

- Example of the output – `clang demo-stdout.c -o demo-stdout`

```
./demo-stdout;  echo $?
Program has been called as ./demo-stdout
1st argument is not given
At least one argument must be given!
255
```

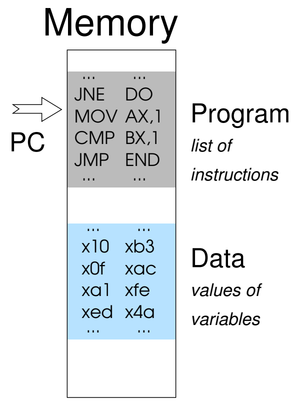
```
./demo-stdout 2>stderr
Program has been called as ./demo-stdout
1st argument is not given

./demo-stdout ARGUMENT 1>stdout; echo $?
0
```


Computers with Program Stored in the Operating Memory

- A sequence of instructions is read from the computer operating memory
- It provides great flexibility in creating the list of instructions

  The program can be arbitrarily changed
- The computer architectures with the shared memory for data and program
  - Von Neumann architecture

    John von Neumann (1903–1957)
  - Program and data are in the same memory type
  - Address of the currently executed instruction is stored in the Program Counter (**PC**)



- The architecture also allows that a pointer can address not only to data but also to the part of the memory where the program is stored

  Pointer to a function

Basic Memory Organization

- The memory of the program can be categorized into five parts
- **Stack** – local variables, function arguments, return value

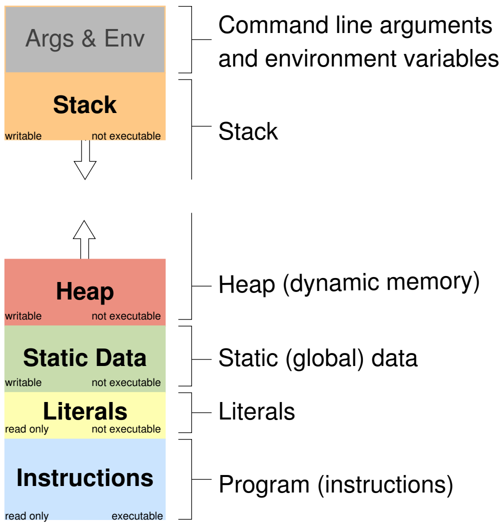
  Automatically managed
- **Heap** – dynamic memory (`malloc()`, `free()`)

  Managed by the programmer
- **Static** – global or "local" `static` variables

  Initialized at the program start
- **Literals** – values written in the source code, e.g., strings

  Initialized at the program start
- **Program** – machine instructions

  Initialized at the program start



Scope of Local Variables

- Local variables are declared (and valid) inside a block or function

```c
1  int a = 1;  // global variable
2
3  void function(void)
4  { // here, a represents the global variable
5     int a = 10; // local variable a shadowing the global a
6     if (a == 10) {
7        int a = 1;  // new local variable a; access to the
8                    // former local a is shadowed
9        int b = 20; // local variable valid inside the block
10       a = b + 10; // the value of the variable a is 11
11    } // end of the block
12    // here, the value of a is 10, it is the local
13    // variable from the line 5
14
15    b = 10; // b is not valid (declared) variable
16 }
```

- Global variables are accessible "everywhere" in the program, but they can be shadowed by a local variable of the same name, which can be solved by the specifier `extern` in a block

http://www.tutorialspoint.com/cprogramming/c_scope_rules.htm

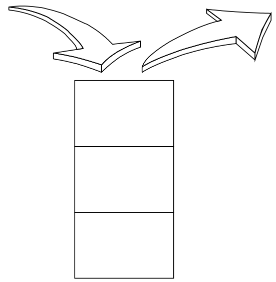
Variables and Memory Allocation

- Memory allocation is determination of the memory space for storing variable value
- For local variables a function arguments the memory is allocated during the function call
  - The memory is allocated until the function return
  - It is automatically allocated from reserved space called **Stack**

    The memory is released for the further usage.
  - The exceptions are local variables with the specifier `static`
    - Regarding the scope, they are local variables
    - But the value is preserved after the function/block end
    - They are stored in the static part of the memory
- Dynamic allocation of the memory – library, e.g., `<stdlib.h>`
  - The memory allocation is by the **malloc()** function

    Alternative memory management libraries exist, e.g., with garbage collector – boehm-gc
  - The memory is allocated from the reserved part of the memory called **Heap**

Stack



- Memory blocks allocated to local variables and function arguments are organized in into **stack**
- The memory blocks are "pushed" and "popped"
  - The last added block is always popped first

    LIFO – last in, first out
- The function call is also stored in the stack

  The return value and also the value of the "program counter" denoted the location of the program at which the function has been called.
- The variables for the function arguments are allocated on the stack

By repeated recursive function call, the memory reserved for the stack can be depleted, and the program is terminated with an error

Recursive Function Call – Example

```
#include <stdio.h>

void printValue(int v)
{
   printf("value: %i\n", v);
   printValue(v + 1);
}

int main(void)
{
   printValue(1);
}
```

lec03/demo-stack_overflow.c

- Try yourself to execute the program with a limited stack size

```
clang demo-stack_overflow.c
ulimit -s 1000;  ./a.out  | tail -n 3
value: 31730
value: 31731
Segmentation fault

ulimit -s 10000;  ./a.out  | tail -n 3
value: 319816
value: 319817
Segmentation fault
```


Comment – Coding Style and **return** 1/2

- The `return` statement terminates the function call and pass the value (if any) to the calling function

```
int doSomeThingUseful() {
   int ret = -1;
   ...
   return ret;
}
```

- How many times **return** should be placed in a function?

```
int doSomething() {
   if (
         !cond1
      && cond2
      && cond3
      ) {
      ... do some long code ...
   }
   return 0;
}
```

```
int doSomething() {
   if (cond1) {
      return 0;
   }
   if (!cond2) {
      return 0;
   }
   if (!cond3) {
      return 0;
   }
   ... some long code ....
   return 0;
}
```

http://llvm.org/docs/CodingStandards.html

Comment – Coding Style and **return** 2/2

- Calling **return** at the beginning can be helpful

  E.g., we can terminate the function based on the value of the passed arguments.
- Coding style can prescribe to use only a single return in a function

  Provides a great advantage to identify the return, e.g., for further processing of the function return value.
- It is not recommended to use **else** immediately after **return** (or other interruption of the program flow), e.g.,

```
case 10:
   if (...) {
      ...
      return 1;
   } else {
      if (cond) {
         ...
         return -1;
      } else {
         break;
      }
   }
```

```
case 10:
   if (...) {
      ...
      return 1;
   } else {
      if (cond) {
         ...
         return -1;
      }
   }
   break;
```


Variables

- Variables denote a particular part of the memory and can be divided according to the type of allocation
  - **Static** allocation is performed for the definition of **static** and global variables. The memory space is allocated during the program start. The memory is never released (only at the program exit).
  - **Automatic** allocation is performed for the definition of local variables. The memory space is allocated on the **stack**, and the memory of the variable is automatically released at the end of the variable scope.
  - **Dynamic** allocation is not directly supported by the C programming language, but it is provided by library functions

    E.g., `malloc()` *and* `free()` *from the standard C library* `<stdlib.h>` *or* `<malloc.h>`

http://gribblelab.org/CBootcamp/7_Memory_Stack_vs_Heap.html

Variable Declaration

- The variable declaration has general form

  declaration-specifiers declarators;
- Declaration specifiers are:
  - **Storage classes**: at most one of the `auto`, `static`, `extern`, `register`
  - **Type quantifiers**: `const`, `volatile`, `restrict`

    None or more type quantifiers are allowed
  - **Type specifiers**: `void`, `char`, `short`, `int`, `long`, `float`, `signed`, `unsigned`. In addition, `struct` and `union` type specifiers can be used. Finally, own types defined by `typedef` can be used as well.

Reminder from the 1st lecture.

Variables – Storage Classes Specifiers (SCS)

- **auto** (local) – Temporary (automatic) variable is used for local variables declared inside a function or block. Implicit specifier, the variables is on the `stack`.
- **register** – Recommendation (to the compiler) to store the variable in the CPU register (to speedup).
- **static**
  - Inside a block `{...}` – the variable is defined as static, and its value is preserved even after leaving the block It exists for the whole program run. It is stored in the **static (global) part of the data memory** (**static data**).
  - Outside a block – the variable is stored in the **static data**, but its visibility is restricted to a module
- **extern** – extends the visibility of the (static) variables from a module to the other parts of the program Global variables with the `extern` specifier are in the **static data**.

Definitions – Example

- Header file vardec.h

```
extern int global_variable;
```

lec03/vardec.h

- Source file vardec.c

```
#include <stdio.h>
#include "vardec.h"

static int module_variable;
int global_variable;

void function(int p)
{
   int lv = 0; /* local variable */
   static int lsv = 0; /* local static variable */
   lv += 1;
   lsv += 1;
   printf("func: p%d, lv %d, lsv %d\n", p, lv, lsv);
}
int main(void)
{
   int local;
   function(1);
   function(1);
   function(1);
   return 0;
}
```

lec03/vardec.c

- Output

```
func: p 1, lv 1, slv 1
func: p 1, lv 1, slv 2
func: p 1, lv 1, slv 3
```


Comment – Variables and Assignment

- Variables are defined by the type name and name of the variable
  - Lower case names of variables are preferred
  - Use underscore _ or *camelCase* for multi-word names

    https://en.wikipedia.org/wiki/CamelCase
  - Define each variable on a new line

```
int n;
int number_of_items;
```

- The assignment statement is the assignment operating = and ;
  - The left side of the assignment must be the **l-value – location-value, left-value** – it has to represent a memory location where the value can be stored
  - Assignment is an expression, and it can be used whenever an expression of the particular type is allowed *Storing the value to left side is a side effect.*

```
/* int c, i, j; */
i = j = 10;
if ((c = 5) == 5) {
   fprintf(stdout, "c is 5 \n");
} else {
   fprintf(stdout, "c is not 5\n");
}
```

lec03/assign.c

Part III

Part 3 – Assignment HW 03

HW 03 – Assignment

Topic: **Caesar Cipher**

Mandatory: **2 points**; Optional: **2 points**; Bonus : none

- **Motivation**: Experience a solution of the optimization task
- **Goal**: Familiar yourself with the dynamic allocation
- **Assignment**: https://cw.fel.cvut.cz/wiki/courses/b3b36prg/hw/hw03
  - Read two text messages and print decode message to the output
  - Both messages (the encoded message and the poorly received message) have the same length
  - Determine the best match of the decoded and received messages based on the shift value of the Caesar cipher https://en.wikipedia.org/wiki/Caesar_cipher
  - Optimization of the Hamming distance

    https://en.wikipedia.org/wiki/Hamming_distance
  - Optional assignment – an extension for considering missing characters in the received message and usage of the Levenshtein distance

    https://en.wikipedia.org/wiki/Levenshtein_distance
- **Deadline**: 21.03.2020, 23:59:59 PDT *PDT – Pacific Daylight Time*

Summary of the Lecture

Topics Discussed

- Data types
- Arrays
- Pointers
- Memory Classes

- Next: Arrays, strings, and pointers.