System SW

Lecture 5 – Basics of C programming language – Part 4

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Lecture 7 – Basics of C programming language – Part 4

- Review
- Pointers (cont)
- C operators
- Conditional execution

Review of last lecture

- Data types array & string
- Type qualifiers
- Storage classes
- Type casting
- Pointers

Review: Arrays

- An array is a container for data which is of all the **same** type
- The data type can be a basic type (integer, char etc) or a derived type (struct, pointer, another array etc)
- Defined by square brackets **[ ]**
- Static arrays: The size of an array is known at the compile time
- Dynamic arrays involve the use of pointers and malloc() to allocate memory from the heap memory area (will be covered later on)

```
//Declaration
type name[number of elements];
int numbers[6];

//Declaration + initialization
type name[number of elements]=
{comma-separated values};

int point[6]={0,0,1,0,0,0};

//When initializing at declaration,
//size can be omitted
int point[]={0,0,1,0,0,0};

//Multi-dimensional arrays
char two_d[2][3];

int two_d[][] = {
          { 5, 2, 1 },
          { 6, 7, 8 }
};
```

Review: Strings in C

- There is no string type in C – instead, strings are stored in **character arrays**
- A string is **terminated** by a null- character '\0', which is automatically added to the end by compiler in the first example
- In the latter example null-character needs to be inserted manually
- All the string library functions expect strings to be terminated by a null-character
- String indexing starts from zero
- String handling routines are in string library <string.h> (along with useful memory handling routines)

```
char string[5] = "Blaa";

char string[5] = {'B','l','a','a','\0'};
```

0	1	2	3	4
B	l	a	a	\0

```
#include <stdio.h>
int main()
{
    char string1[5] = "Blaa";
    char string2[5] = {'B','l','a','a','\0'};
    char string3[4] = "Blaa"; //no!!!
    printf("%s\n",string1);
    printf("%s\n",string2);
    printf("%s\n",string3);
    return 0;
}
```

```
Blaa
Blaa
Blaa
```

← Oops!

https://www.tutorialspoint.com/c_standard_library/string_h.htm

Review: Type qualifiers / volatile

- All variables are considered ”unqualified” by default - Type qualifiers modify the properties of variables in certain ways
- C has 4 type qualifiers:
  - Const
  - volatile (C89)
  - restrict (C99, skipped)
  - _Atomic (C11, skipped)
- const
  - Enables optimization, value cannot change, storage to code memory
- volatile
  - Tells the compiler: Do not optimize because variable value can change out of context, any time
  - Use with variables which are used by interrupt handlers

Review: Storage classes of variables and functions

- Storage Classes are used to describe about the features of a variable/function.

- 4 storage classes:

static

functions can be called only from the same .c-file

variables preserve their value even after they are out of scope

auto - a local variable in a function body (default, so you don't have to use this ever)

extern - tells compiler that the variable is defined elsewhere (default for globals)

register - a hint to compiler to cache the variable in a processors register.
Avoid, if you are not smarter than compiler

RULE: don't use keyword **auto** – it's completely useless

RULE: use keyword **static** whenever possible

(Barr: C coding standard 2018)

Review: C type casting

- Type casting is a way to convert a variable from one data type to another explicitly using the **cast operator**

  (type_name) expression

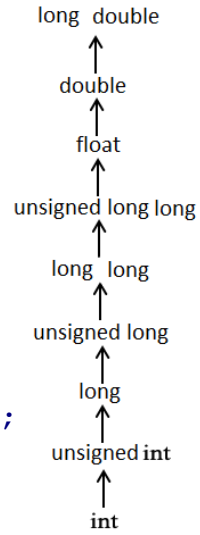
- Compiler does automatic conversions from smaller integer types to larger types, this is called **integer promotion**

- Casting is potentially dangerous! If you cast a ”large” value to a ”smaller” data type, data loss will happen

- RULE: Each cast shall feature an associated comment describing how the code ensures proper behavior across the range of possible values on the right side

```
main() {
    int sum = 17, count = 5;
    double mean;
    mean = (double) sum / count;
    printf("Value of mean: %f\n",mean);
}
```

```
main() {
    int  i = 17;
    char c = 'c'; //ascii: 99
    float sum;
    sum = i + c;
    printf("Value of sum: %f\n",sum);
}
```



Review: Pointers

- Each variable in your program is stored in the memory – in other words, it has a memory location (an address)
- What is a pointer?
  - A **pointer** is a variable whose **value** is the **address** of another variable, i.e., address of a memory location
  - A pointers value can be also an address of a function – then it is called a **function pointer**
- The variable address &var is stored to a pointer variable i_p
- And the value of the variable the pointer is pointing to, can be read with * – this is called **dereferencing**

Pointer variable declaration:

```
data_type * name_p;

int * i_p;        // pointer to an integer
my_struct_t * struct_p; /* pointer to my_struct type */
```

Assign a value with address-of **&**

```
int  var = 20; //variable declaration
int * i_p;     //pointer variable decl.
i_p = &var;    //store address of var to i_p
```

Dereferencing *i_p gives you value-at-address stored in a pointer variable

```
printf("Value of *i_p variable: %d\n", *i_p );
```

Review: Pointers with structs – an example

```c
#include <stdio.h>
#include <stdint.h>
#include <string.h>

typedef struct {
   char title[50];
   int book_id;
} Book_t;

#define NUMBER_OF_BOOKS 3

int main()
{
    Book_t library[NUMBER_OF_BOOKS]; //create array of books
    Book_t * my_ptr;       //Pointer declaration operator (points to Book_t type)
    my_ptr = &library[0];  // Address-of operator picks the
                           // address of library and assigns it to my_ptr

    //Let's check what's the size of Book_t
    printf("Size of Book_t:\t%d bytes.\n\n",sizeof(Book_t));

    //populate the library with books
    const char title_base[] = "Name of the book ";
    char letter[2] = {'A','\0'};
    for (uint8_t i=0; i<NUMBER_OF_BOOKS; i++) {

        strcpy(&my_ptr->title[0], &title_base[0]);
        strcat(&my_ptr->title[0], &letter[0]);

        my_ptr->book_id = 1000+i;
        letter[0]++; //pick the next letter
        my_ptr++; //increment the pointer to next "book slot" in the library
     }

    //Run inventory for the library

       //roll back the pointer to first book in library
       my_ptr = &library[0];

       printf("Contents of the library:\n\n");
       printf("Book Title:\t\tBook id:\n");
       for (uint8_t i=0; i<NUMBER_OF_BOOKS; i++) {
           printf("%s\t%d\n",my_ptr->title,my_ptr->book_id);
           my_ptr++; //increment the pointer
                     // to next "book slot" in the library
        }

       return 0;

}
```

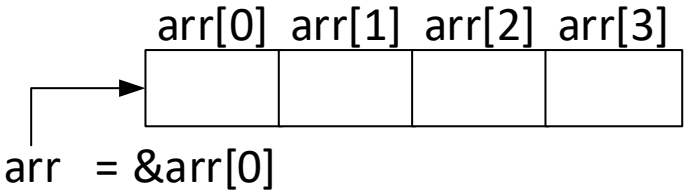
```
Size of Book_t: 56 bytes.

Contents of the library:

Book Title:             Book id:
Name of the book A      1000
Name of the book B      1001
Name of the book C      1002
```

Recap: Relation between arrays and pointers

- C does not have array variables (or string variables, which are char arrays)
- In fact, the array notation [] is actually an alternate way of using pointers
- Consider an array: int arr[4]
- Name of the array always points to the first element [0] of array
- This means that arr is equivalent to &arr[0]
- Futhermore, statement
  arr[2] =5; is identical to
  *(arr+2) = 5;
- So arr is already a pointer!
- BUT, it is a constant pointer, you cannot apply arithmetics to the name of an array!



Note: strcpy is a function that take pointer arguments

```
char *strcpy(char *dest, const char *src)
```

```
strcpy(&my_ptr->title[0], &title_base[0]);
```

my_prt->title is an character **array**, so are *title_base* and *letter* – they are already pointers

Therefore, we don't need &-operator

```
strcpy(my_ptr->title, title_base);
```

Lecture 7 – Basics of C programming language – Part 4

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- Pointers (cont)
- C operators
- Conditional execution

Pointers – some coding rules

- At the declaration, pointers should be always initialized to NULL
- This way you can test for possible NULL-pointers before deferencing them (or worse: jumping to that memory address if it was a function pointer)
- Naming convention: use _p for all the pointers! This helps you avoid many bugs as you don't accidentally assign a value for the pointer, when the intention was to dereference it
- Coding guideline:
  - When declaring pointers, use whitespace before and after '*'
  - When using &-operator, tie it to the operand
  - When dereferencing tie * to the operand (pointer variable)

```
// pointer to an integer, initialized to NULL
int * i_p = NULL;

if(i_p) {"not NULL, move on"}

if(!i_p) {"error, do something"}
```

```
Int * i_p = NULL;

i_p = &var;

*i_p = 50;
```

NULL pointers

- On most of the operating system, programs are not permitted to access memory at address 0, because the memory location is reserved by the OS
- Memory address 0 has a special significance: it signals that the pointer is not intended to point to an accessible memory location
- You can use null pointers as markers, for example to indicate the end of a linked list, or to test if memory allocation failed

```
int *x_p = malloc(32);
if(!x_p)
{
    printf("memory allocation failed!");
}
```

Void pointers

- A void pointer is a pointer that
  - has no associated data type with it
  - can hold address of any type
  - can be typecasted to any type
- Used to implement generic functions
- For example malloc() returns a void pointer to the allocated memory location
  - Can be typecasted to any type
  - In C, automatic casting takes place

```
int a = 10;
char b = 'x';

void *x_p = &a;  // void pointer
holds address of int 'a'
x_p = &b; // void pointer holds
address of char 'b'
```

```
int *x_p = malloc(sizeof(int) * 16);
```

```
int *x_p = (int *) malloc(sizeof(int) * 16);
```

Pointer arithmetics

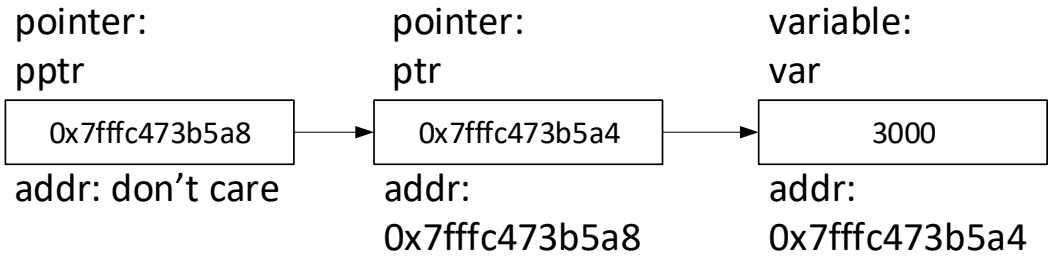
- C pointer is a variable that holds a numeric value (an address), which means that you can perform arithmetic operations to it
  - Four arithmetic operators can be used with pointers: +, - , ++, --
- At the declaration of the pointer variable, the data type is defined. Therefore, when incrementing the value of the pointer, it takes the size of the data type into account

```
typedef struct {char title[50];
   int book_id; } Book_t;

    uint64_t delta_addr;
    Book_t library[5];
    Book_t * my_ptr, * my_ptr2;
    my_ptr = &library[0];
    my_ptr2 = my_ptr;
    my_ptr2++;
    //Let's check what's the size of Book_t
    printf("Size of Book_t:\t%lu bytes.\n\n",sizeof(Book_t));
    printf("ptr1: 0x%lx\nptr2: 0x%lx\n",my_ptr,my_ptr2);

    delta_addr = my_ptr2-my_ptr; //delta in book_t's
    printf("ptr2-ptr1: %lu\n",delta_addr);
    //cast pointers to integers
    delta_addr = (uint64_t)my_ptr2-(uint64_t)my_ptr;
    //now we see delta in bytes
    printf("ptr2-ptr1: %lu\n",delta_addr);
```

```
Size of Book_t: 56 bytes.

ptr1: 0x7ffc9dcff370
ptr2: 0x7ffc9dcff3a8
ptr2-ptr1: 1
ptr2-ptr1: 56
```

Pointers to pointers

- A pointer to pointer is a form of multiple indirection
- Normally, a pointer contains the address of a variable, but it can also contain an address of another pointer variable




```
int var;
int * ptr;
int ** pptr;
var = 3000;
ptr = &var; // take the address of var
pptr = &ptr;  // take the address of ptr
printf("Address of var = %lx\n", &var );
printf("Address of ptr = %lx\n", &ptr );
printf("Value of var = %d\n", var );
printf("Value available at *ptr = %d\n", *ptr );
printf("Value available at **pptr = %d\n", **pptr);
```

```
Address of var = 7fffc473b5a4
Address of ptr = 7fffc473b5a8
Value of var = 3000
Value available at *ptr = 3000
Value available at **pptr = 3000
```

Pointers are so complex – why all the hassle?

- Instead of passing large amounts of data to functions (and returning it back), functions can take pointers as argument allowing the function to manipulate data directly in that memory location
  - Less memory transfer/copy operations -> faster code!
- By default, C uses ”call by value” to pass arguments to functions – in this case changes to made to the parameter inside function has no effect on the argument
- ”Call by reference” means that the address of the argument (i.e. the pointer) is passed to the function, which can directly alter the value of the argument
  - We’ll revisit this when covering functions

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C operators

- Used to assign, compare and modify data
- Unary, binary and ternary operators (i.e. takes one, two or tree operands)
- Some operators can be combined with assignment -> compound operators
- Precedence rules (order of operations) are not very clear – use parenthesis () when in doubt!

Type	Operators
Logical	||, &&, !
Bitwise	<<, >>, |, &, ^, ~
Arithmetic	+, -, /, *, ++, --, %
Relational	<, <=, >, =>, ==, !=

Logical operators

Type	Operators
Logical	||, &&, !
Bitwise	<<, >>, |, &, ^, ~
Arithmetic	+, -, /, *, ++, --, %
Relational	<, <=, >, =>, ==, !=

Boolean conditions:
False = any condition that is **zero**
True = any condition that is **non-zero**

```
|| = logical OR
&& = logical AND
!  = logical NOT

if ( condition1 || condition2 )
if ( condition1 && condition2 )
while ( ! condition )
```

Bitwise operators

Type	Operators
Logical	||, &&, !
Bitwise	<<, >>, |, &, ^, ~
Arithmetic	+, -, /, *, ++, --, %
Relational	<, <=, >, =>, ==, !=

<< = Left Shift
>> = Right Shift
| = Bitwise OR
& = Bitwise AND
^ = Bitwise XOR
~ = One's Complement

```
foo = varA >> 4;
foo = varA | varB;
foo = varA & varB;
foo = varA ^ varB;
foo = ~varA;
```

Right-Shift (logical)
`varA >> 4` → Right Shift 4 bits

Ex: `0b10010110 >> 4`

= `0b00001001` **(zeros shifted in)**
(lower bits truncated)

AND
`foo = varA & varB;`

varA = 0xF5; →	1	1	1	1	0	1	0	1
varB = 0x5B; →	0	1	0	1	1	0	1	1
foo = 0x51 →	0	1	0	1	0	0	0	1

Arithmetic operators

Type	Operators
Logical	||, &&, !
Bitwise	<<, >>, |, &, ^, ~
Arithmetic	+, -, /, *, ++, --, %
Relational	<, <=, >, =>, ==, !=

```
+  = Addition
-  = Subtraction
/  = Divide
*  = Multiply
++ = Increment
-- = Decrement
%  = Modulus
```

```
foo = varA + varB;
foo = varA - varB;
foo = varA * varB;
foo = varA % 2;
foo = varA++;
```

Modulus Operator (Remainder)
15 % 4 -> 3

Increment/Decrement
varA++ -> varA = varA + 1;
varA-- -> varA = varA - 1;

Relational operators

Type	Operators
Logical	||, &&, !
Bitwise	<<, >>, |, &, ^, ~
Arithmetic	+, -, /, *, ++, --, %
Relational	<, <=, >, =>, ==, !=

```
<    = Less-Than
<=   = Less-Than Or Equal to
>    = Greater-Than
>=   = Greater-Than or Equal to
==   = Equal to
!=   = Not Equal To
```

Concerning equivalence checks

```
//Beware of these nasty mistakes:
if (a=0) {…}
```

This will set **a** to zero, instead of testing it against zero, the result is always true! Difficult to catch, but at least most compilers or even editors give you a warning, but not all.

```
//Place constant to left side instead:
if (0=a) {…}
```

Now we try to assing a value to constant, which will immediately cause compiler error

```
//Preferably, don't make mistakes ;)
if (0==a) {…}
```

Conditional operator ?:

- The only ternary operator in C
- Also known as inline if (iif) or ternary if
- Just a shorter notification, does not make your code any better
- You cannot set a breakpoint to either case
- Think twice before showing off with ?:

```
res = (a > b) ? x : y;

evaluates to

if (a>b) {
        res = x;
} else {
        res = y;
}
```

Compound assignment operators

- Syntactically, it is possible to combine assignment with bitwise or arithmetic operators
- Think: Do they really make your code more readable and less prone to errors?

Addition assignment	a += b	a = a + b
Subtraction assignment	a -= b	a = a - b
Multiplication assignment	a *= b	a = a * b
Division assignment	a /= b	a = a / b
Modulo assignment	a %= b	a = a % b
Bitwise AND assignment	a &= b	a = a & b
Bitwise OR assignment	a |= b	a = a | b
Bitwise XOR assignment	a ^= b	a = a ^ b
Bitwise left shift assignment	a <<= b	a = a << b
Bitwise right shift assignment	a >>= b	a = a >> b

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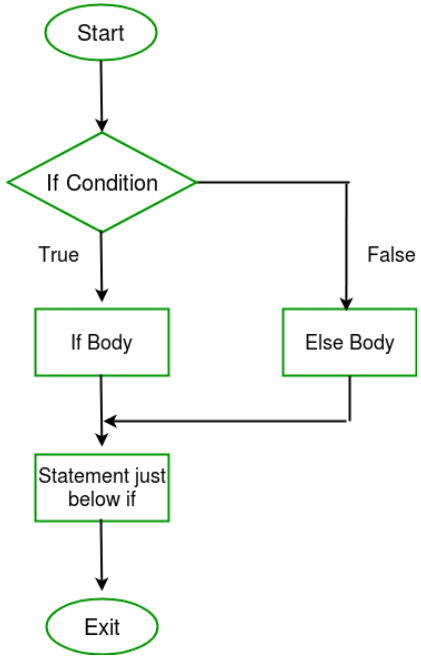
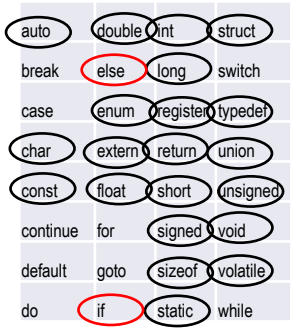
if-else statements

- An **if statement** consists of a boolean expression followed by one or more statements
- An **if statement** can be followed by an optional **else statement**, which executes when the Boolean expression is false




```
int main() {
    int i = 20;
    if (i < 15) {
        printf("i is smaller than 15\n");
    } else {
        printf("i is greater than 15\n");
    }
    printf("Always prints this\n");
    return 0;
}
```



Practical tip

```
if (a==b) c++;
```

Works, but you cannot set a breakpoint when the condition is true -> difficult to debug -> put the statement on it's own code line

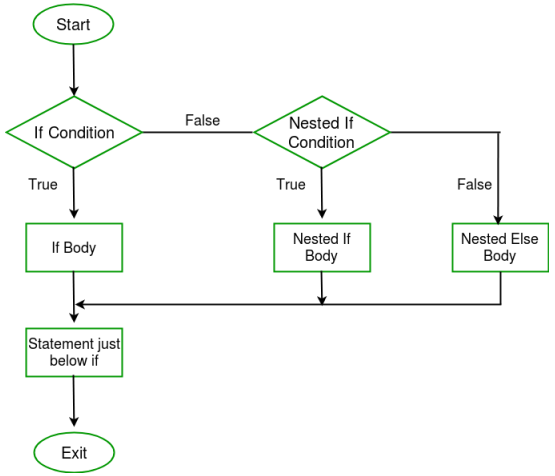
```
if (a==b)
    c++;
```

Now we can set a breakpoint on this line!

Use of curly brackets {} is not mandatory in if-else with one line only, but it is strongly preferred anyway!

Nested if-else

- You can use one **if** or **else if** statement inside another **if** or **else if** statement(s)
- Gets easily quite complex to follow – consider switch-case statements instead

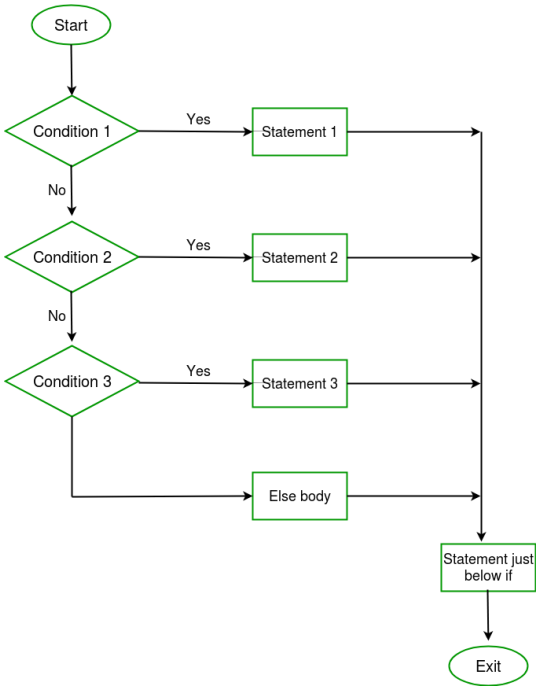



```c
int main() {
    int i = 10;

    if (i == 10) {
        if (i < 15)
            printf("i is smaller than 15\n");

        if (i < 12)
            printf("i is smaller than 12 too\n");
        else
            printf("i is greater than 15\n");
    }
    return 0;
}
```

if-else if -ladder

- In case you need to decide among multiple options
- Only one statement will be executed
- This is clearly a place for switch-case

```
int main()
{
    int i = 20;

    if (i == 10)
        printf("i is 10");
    else if (i == 15)
        printf("i is 15");
    else if (i == 20)
        printf("i is 20");
    else
        printf("i is something else");
}
```



switch – case

- Switch case statements are a substitute for long if statements that compare a variable to several integral values
- Note: only constant cases allowed – (enumerated values are constants)
- Remember ”break” at the end of each case
- Default case: if no other cases matched

```
switch (x){
  case 1: printf("Choice is 1");
          break;
  case 2: printf("Choice is 2");
          break;
  default: printf("Choice was other than 1 or 2");
           break;
}
```