Writing Program in C
Expressions and Control Structures (Statements and Loops)

Jan Faigl

Department of Computer Science
Faculty of Electrical Engineering
Czech Technical University in Prague

Lecture 02

B0B36PRG – Programming in C

Overview of the Lecture

- Part 1 – Expressions
  - Expressions – Literals and Variables
  - Expressions – Operators
  - Associativity and Precedence
  - Assignment

  K. N. King: chapter 4 and 20
- Part 2 – Control Structures: Selection Statements and Loops
  - Statements and Coding Styles
  - Selection Statements
  - Loops
  - Conditional Expression

  K. N. King: chapters 5 and 6
- Part 3 – Assignment HW 01
- Part 4 – Coding example (optional)

Part I

Part 1 – Expressions

Expressions

- **Expression** prescribes calculation value of some given input.
- Expression is composed of **operands**, **operators**, and **brackets**.
- Expression can be formed of
  - literals,
  - variables,
  - constants,
  - unary and binary operators,
  - function call,
  - brackets.
- The order of operation evaluation is prescribed by the operator **precedence** and **associativity**.

```
10 + x * y      // order of the evaluation 10 + (x * y)
10 + x + y      // order of the evaluation (10 + x) + y
```

** has higher priority than +*
+ is associative from the left-to-right

- The evaluation order can be prescribed by **fully parenthesized expression**.

Simply: If you are not sure, use brackets.

Literals – Integer and Rational

- Integer values are stored as one of the integer type (keywords): `int`, `long`, `short`, `char` and their `signed` and `unsigned` variants. *Further integer data types are possible.*
- Rational numbers (data types `float` and `double`) can be written with floating point – `13.1`; or with mantissa and exponent – `31.4e-3` or `31.4E-3`. *Scientific notation*
- Floating point numeric types depends on the implementation (usually as IEEE-754-1985).

Integer literals (values)

Decimal	123 450932	
Hexadecimal	0x12 0xFAFF	(starts with `0x` or `0X`)
Octal	0123 0567	(starts with `0`)
`unsigned`	12345U	(suffix `U` or `u`)
`long`	12345L	(suffix `L` or `l`)
`unsigned long`	12345ul	(suffix `UL` or `ul`)
`long long`	12345LL	(suffix `LL` or `ll`)

Without suffix, the literal is of the type typu `int`.

Rational literals

- `double` – by default, if not explicitly specified to be another type;
- `float` – suffix `F` or `f`;

```
float f = 10.f;
```

- `long double` – suffix `L` or `l`.

```
long double ld = 10.1l;
```


Literals – Characters and Text Strings

- Character literal is single (or multiple) character in apostrophe.
  `'A'`, `'B'` or `'\n'`
- Value of the single character literal is the ASCII code of the character.
  `'0'`∼ 48, `'A'`∼ 65
  Value of character out of ASCII (greater than 127) depends on the compiler.
- Type of the character constant (literal).
  - **Character constant is the `int` type.**

```
char c = '8';  // Letter of the digit 8
int v = c - '0'; // Conversion to int value 8

char a = '0'; // Test a letter is upper case
_Bool upper = (a >= 'A' && a <= 'Z');

char i = '5'; // Test a letter is a digit
_Bool digit = (i >= '0' && i <= '9');
```

- Text string is a sequence of characters enclosed in quotation marks.
  `"A string with the end of line \n".`
  - String literals separated by white spaces are joined to single one.
  `"A string literal" "with the end of the line \n"`
  is concatenate into
  `"A string literal with end of the line \n"`
- String literal is stored in the array of the type `char` terminated by the `null` character `'\0'`.
  A string literal `"word"` is stored as

'w'	'o'	'r'	'd'	'\0'

The size of the array must be ***+1 item longer*** *to store `\0`!*

Literals – Enumeration

- By default, values of the enumerated type starts from 0 and each other item increase the value about one, values can be explicitly prescribed.

```
enum {
   WHITE,
   BLACK,
   RED,
   GREEN,
};
```

```
enum {
   ERROR_OK = 0, // EXIT_SUCCESS
   ERROR_INPUT = 100,
   ERROR_RANGE = 101
};
```

The enumeration values are usually written in uppercase.

- Type – enumerated constant is the `int` type.
  - Value of the enumerated literal can be used in loops.

```
enum { WHITE = 0, BLACK, RED, GREEN, BLUE, NUM_COLORS };

for (int color = WHITE; color < NUM_COLORS; ++color) {
   ...
}
```


Variable Definition

- The variable definition has a general form
  declaration-specifiers variable-identifier;
- Declaration specifiers are following.
  - **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`, `double`, `signed`, `unsigned`.
    In addition, `struct` and `union` type specifiers can be used. Finally, own types defined by `typedef` can be used as well.

```
float f = 10.1f; // float variable initialized by float literal
const double pi = 3.14; //const double variable initialized to 3.14
unsigned char v = 255; //one byte integer variable with the full range 0..255
const unsigned long l = 1001; //constant long integer variable initialized by long literal
int i; // i variable of the common C integer type int that is not initialized
```

Operators

- Operators are selected characters (or sequences of characters) dedicated for writting expressions.
- Five types of binary operators can be distinguished.
  - **Arithmetic** operators – additive (addition/subtraction) and multiplicative (multiplication/division);
  - **Relational** operators – comparison of values (less than, greater than, ...);
  - **Logical** operators – logical `AND` and `OR`;
  - **Bitwise** operators – bitwise `AND`, `OR`, `XOR`, bitwise shift (left, right);
  - Assignment operator = – a variables (l-value) is on its left side.
- Unary operators
  - Indicating positive/negative value: + and −.

    Operator − modifies the sign of the expression.
  - Modifying a variable : ++ and −−.
  - Logical negation: !.
  - Bitwise negation: ∼.
- Ternary operator – conditional expression ? :.

Variables, Assignment Operator, and Assignment Statement

- Variables are defined by the type and name.
  - Name of the variable are in lowercase.
  - Multi-word names can be written with underscore _. *Or we can use CamelCase.*
  - Each variable is defined at a new line.

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

- Assignment is setting the value to the variable, i.e., the value is stored at the memory location referenced by the variable name.
- Assignment operator

  ⟨**l-value**⟩ = ⟨**expression**⟩

  Expression is literal, variable, function calling, ...
  - The side is the so-called **l-value – location-value, left-value**

    It must represent a memory location where the value can be stored.
  - Assignment is an expression and we can use it everywhere it is allowed to use the expression of the particular type.
- Assignment statement is the assignment operator = and ;.

Basic Arithmetic Expressions

- For an operator of the numeric types `int` and `double`, the following operators are defined.

  Also for `char`, `short`, and `float` numeric types.
  - Unary operator for changing the sign −;
  - Binary addition + and subtraction −;
  - Binary multiplication * and division /.
- For integer operator, there is also
  - Binary module (integer reminder) %.
- If both operands are of the same type, the results of the arithmetic operation is the same type.
- In a case of combined data types **int** and **double**, the data type `int` is converted to **double** and the results is of the **double** type.

  Implicit type conversion.

Example – Arithmetic Operators 1/2

```
int a = 10;
int b = 3;
int c = 4;
int d = 5;
int result;

result = a - b; // subtraction
printf("a - b = %i\n", result);

result = a * b; // multiplication
printf("a * b = %i\n", result);

result = a / b; // integer divison
printf("a / b = %i\n", result);

result = a + b * c; // priority of the operators
printf("a + b * c = %i\n", result);

printf("a * b + c * d = %i\n", a * b + c * d);          // -> 50
printf("(a * b) + (c * d) = %i\n", (a * b) + (c * d)); // -> 50
printf("a * (b + c) * d = %i\n", a * (b + c) * d);      // -> 350
```

lec02/arithmetic_operators.c

Example – Arithmetic Operators 2/2

```c
#include <stdio.h>

int main(void)
{
   int x1 = 1;
   double y1 = 2.2357;
   float x2 = 2.5343f;
   double y2 = 2;

   printf("P1 = (%i, %f)\n", x1, y1);
   printf("P1 = (%i, %i)\n", x1, (int)y1);
   printf("P1 = (%f, %f)\n", (double)x1, (double)y1);
   printf("P1 = (%.3f, %.3f)\n", (double)x1, (double)y1);

   printf("P2 = (%f, %f)\n", x2, y2);

   double dx = (x1 - x2); // implicit data conversion to float
   double dy = (y1 - y2); // and finally to double

   printf("(P1 - P2)=(%.3f, %0.3f)\n", dx, dy);
   printf("|P1 - P2|^2=%.2f\n", dx * dx + dy * dy);
   return 0;
}
```

lec02/points.c

Arithmetic Operators

- Operands of arithmetic operators can be of any arithmetic type.

*The only exception is the operator for the integer reminder % defined for the **int** type.*

*	Multiplication	`x * y`	Multiplication of x and y
/	Division	`x / y`	Division of x and y
%	Reminder	`x % y`	Reminder from the x / y
+	Addition	`x + y`	Sum of x and y
-	Subtraction	`x - y`	Subtraction x and y
+	Unary plus	`+x`	Value of x
-	Unary minus	`-x`	Value of −x
++	Increment	`++x/x++`	Incrementation before/after the evaluation of the expression x
--	Decrement	`--x/x--`	Decrementation before/after the evaluation of the expression x

Integer Division

- The results of the division of the operands of the **int** type is the integer part of the division.

E.g.. 7/3 is 2 and −7/3 is −2

- For the integer reminder, it holds $x\%y = x - (x/y) * y$.

E.g., 7 % 3 is 1   -7 % 3 is -1   7 % -3 is 1   -7 % -3 is -1

- **C99**: The result of the integer division of negative values is the value closer to 0.
  - It holds that (a/b)*b + a%b = a.

For older versions of C, the results depends on the compiler.

Implementation-Defined Behaviour

- The C standard deliberately leaves parts of the language unspecified.
- Thus, some parts depend on the implementation, such as compiler, environment, or computer architecture.

E.g., Reminder behavior for negative values and version of the C prior C99.

- The reason for that is the focus of C on efficiency, i.e., match the hardware behavior.
- Having it in mind, it is best to avoid writing programs that depend on implementation-defined behavior.

K.N.King: Page 55

That is one example of writting programs that seem to be working and functional and a program that is correct.

Unary Arithmetic Operators

- Unary operator (++ and −−) change the value of its operand.

  The operand must be the `l-value`, i.e., an expression that has memory space, where the value of the expression is stored, e.g., a variable.

  - It can be used as **prefix** operator, e.g., ++**x** and −−**x**;
  - or as **postfix** operator, e.g., **x**++ and **x**−−.
  - In each case, the final value of the expression is different!

int i; int a;	**value of i**	**value of a**
i = 1; a = 9;	**1**	**9**
a = i++;	**2**	**1**
a = ++i;	**3**	**3**
a = ++(i++);	**Not allowed! Value of i++ is not the l-value**	

For the unary operator `i++`, it is necessary to store the previous value of `i` and then the variable `i` is incremented. The expression `++i` only increments the value of `i`. Therefore, `++i` can be more efficient.

Relational Operators

- Operands of relational operators can be of arithmetic type, pointers (of the same type) or one operand can be `NULL` or pointer of the `void` type.

<	Less than	`x < y`	1 if x is less than y; otherwise 0
<=	Less than or equal	`x <= y`	1 if x is less then or equal to y; otherwise 0
>	Greater than	`x > y`	1 if x is greater than y; otherwise 0
>=	Greater than or equal	`x >= y`	1 if x is greater than or equal to y; otherwise 0
==	Equal	`x == y`	1 if x is equal to y; otherwise 0
!=	Not equal	`x != y`	1 if x is not equal to y; otherwise 0

Logical operators

- Operands can be of arithmetic type or pointers.
- Resulting value `1` means `true`, `0` means `false`.
- In the expressions `&&` (Logical AND) and `||` (Logical OR), the left operand is evaluated first.
- If the results is defined by the left operand, the right operand is not evaluated.

  Short-circuiting behavior *– it may speed evaluation of complex expressions in runtime.*

&&	Logical AND	`x && y`	1 if x and y is not 0; otherwise 0.
||	Logical OR	`x || y`	1 if at least one of x, y is not 0; otherwise 0.
!	Logical NOT	`!x`	1 if x is 0; otherwise 0.

- **Operands && a || have the short-circuiting behavior**, i.e., the second operand is not evaluated if the result can be determined from the value of the first operand.

Example – Short-Circuiting Behaviour 1/2

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

int fce_a(int n);
int fce_b(int n);

int main(int argc, char *argv[])
{
   if (argc > 1 && fce_a(atoi(argv[1])) && fce_b(atoi(argv[1])) )
   {
      printf("Both functions fce_a and fce_b pass the test\n");
   } else {
      printf("One of the functions does not pass the test\n");
   }
   return 0;
}

int fce_a(int n)
{
   printf("Calling fce_a with the argument '%d'\n", n);
   return n % 2 == 0;
}

int fce_b(int n)
{
   printf("Calling fce_b with the argument '%d'\n", n);
   return n > 2;
}
```

lec02/demo-short_circuiting.c

Example – Short-Circuiting Behaviour 2/2 – Tasks

In the example `lec02/demo-short_circuiting.c`

- Test how the logical expressions (a function call) are evaluated.
- Identify what functions `fce_a()` and `fce_b()` are implementing.
- Rename the functions appropriately.
- Identify the function headers and why they have to be stated above the main function.
- Try to split implementation of the functions to a separate module.

Bitwise Operators

- Bitwise operators treat operands as a series of bits.

Low-Level Programming – A programming language is low level when its programs require attention of the irrelevant. K.N.King: Chapter 20.

&	Bitwise AND	`x & y`	1 if x and y is equal to 1 (bit-by-bit)
|	Bitwise inclusive OR	`x | y`	1 if x or y is equal to 1 (bit-by-bit)
^	Bitwise exclusive or (XOR)	`x ^ y`	1 if only x or only y is 1 (bit-by-bit)
~	Bitwise complement (NOT)	`~x`	1 if x is 0 (bit-by-bit)
<<	Bitwise left shift	`x << y`	Shift of x by y bits to the left
>>	Bitwise right shift	`x >> y`	Shift of x by y bits to the right

Bitwise Shift Operators

- Bitwise shift operators shift the binary representation by a given number of bits to the left or right.
  - Left shift – Each bit shifted off a zero bit enters at the right.
  - Right shift – Each bit shift off.
    - a zero bit enters at the left – for positive values or unsigned types.
    - for negative values, the entered bit can be either 0 (logical shift) or 1 (arithmetic shift right). Depends on the compiler.
- Bitwise shift operators have lower precedence than the arithmetic operators!
  - $i << 2 + 1$ means $i << (2 + 1)$

Do not be surprised – parenthesized the expression!

Example – Bitwise Expressions

```
#include <inttypes.h>

uint8_t a = 4;
uint8_t b = 5;

a     dec: 4 bin: 0100
b     dec: 5 bin: 0101
a & b dec: 4 bin: 0100
a | b dec: 5 bin: 0101
a ^ b dec: 1 bin: 0001

a >> 1 dec: 2 bin: 0010
a << 1 dec: 8 bin: 1000
```

`lec02/bits.c`

Operators for Accessing Memory

Here, for completeness, details in the further lectures.

- In C, we can directly access the memory address of the variable. *We need in `scanf()`!*
- The access is realized through a pointer. *It is an integer value, typically `long`.*

It allows great options and also understand data representation and memory access models.

Operator	Name	Example	Result
&	Address	`&x`	Pointer to x
*	Indirection	`*p`	Variable (or function) addressed by the pointer p.
[]	Array subscripting	`x[i]`	`*(x+i)` – item of the array `x` at the position `i`.
.	Structure/union member	`s.x`	Member `x` of the struct/union `s`.
->	Structure/union member	`p->x`	Member `x` of the struct/union addressed by the pointer `p`.

It is not allowed an operand of the & operator is a bit field or variable of the register class, because it has to be addressable memory space.
*Operator of the indirect address * allows to access to the memory using pointers.*

Other Operators

Operator	Name	Example	Result
()	Function call	`f(x)`	Call the function `f` with the argument `x`.
(type)	Cast	`(int)x`	Change the type of `x` to `int`.
sizeof	Size of the item	`sizeof(x)`	Size of `x` in bytes.
? :	Conditional	`x ? y : z`	Do `y` if `x != 0`; otherwise `z`.
,	Comma	`x, y`	Evaluate `x` and then `y`, the result is the result of the last expression.

- The operand of `sizeof()` can be a type name or expression.

```
int a = 10;
printf("%lu %lu\n", sizeof(a), sizeof(a + 1.0));
```

lec02/sizeof.c

- Example of the **comma** operator.

```
for (c = 1, i = 0; i < 3; ++i, c += 2) {
   printf("i: %d c: %d\n", i, c);
}
```


Cast Operator

- Changing the variable type in runtime is called type case.
- Explicit cast is written by the name of the type in `()`, e.g.,

```
int i;
float f = (float)i;
```

- Implicit cast is made automatically by the compiler during the program compilation.
- If the new type can represent the original value, the value is preserved by the cast.
- Operands of the `char`, `unsigned char`, `short`, `unsigned short`, and the bit field types can be used everywhere where it is allowed to use `int` or `unsigned int`.

  C expects at least values of the `int` type.
  - Operands are automatically cast to the `int` or `unsigned int`.

Operators Associativity and Precedence

- Binary operation op is **associative** on the set $\boldsymbol{S}$ if

$$(x \,\mathrm{op}\, y) \,\mathrm{op}\, z = x \,\mathrm{op} (y \,\mathrm{op}\, z), \text{ for each } x, y, z \in \boldsymbol{S}.$$

- For not associative operators, it is required to specify the order of evaluation.
  - Left-associative – operations are grouped from the left.

    E.g., $10 - 5 - 3$ *is evaluated as* $(10 - 5) - 3$.
  - Right-associative – operations are grouped from the right.

    E.g., $3 + 5^2$ *is 28 or* $3 \cdot 5^2$ *is 75 vs* $(3 \cdot 5)^2$ *is 225.*
- The assignment is right-associative.

  E.g., y=y+8.

  First, the whole right side of the operator = is evaluated, and then, the results are assigned to the variable on the left.
- The order of the operator evaluation can be defined by the fully parenthesized expression.

Summary of the Operators and Precedence 1/3

Precedence	Operator	Associativity	Name
1	++	L→R	Increment (postfix)
	−−		Decrementation (postfix)
	()		*Function call*
	[]		*Array subscripting*
	. −>		*Structure/union member*
2	++	R→L	Increment (prefix)
	−−		Decrementation (prefix)
	!		Logical negation
	~		Bitwise negation
	− +		Unary plus/minus
	*		*Indirection*
	&		*Address*
	sizeof		*Size*

Summary of the Operators and Precedence 2/3

Precedence	Operator	Associativity	Name
3	()	R→L	*Cast*
4	*, /, %	L→R	Multiplicative
5	+ −−		Additive
6	>>, <<		Bitwise shift
7	<, >, <=, >=		Relational
8	==, !=		Equality
9	&		Bitwise AND
10	ˆ		Bitwise exclusive OR (XOR)
11	|		Bitwise inclusive OR (OR)
12	&&		Logical AND
13	||		Logical OR

Summary of the Operators and Precedence 3/3

Precedence	Operator	Associativity	Name
14	? :	R→L	Conditional
15	=		Assignment
	+=, -=		additive
	*=, /=, %=	R→L	multiplicative
	<<=, >>=		bitwise shift
	&=, ˆ=, |=		Bitwise AND, XOR, OR
15	,	L→R	Comma

K. N. King: Page 735

http://en.cppreference.com/w/c/language/operator_precedence

Simple Assignment

- Set the value to the variable.

  Store the value into the memory space referenced by the variable name.
- The form of the assignment operator is

  ⟨variable⟩ = ⟨expression⟩

  Expression is literal, variable, function call, . . .
- C is statically typed programming language.
  - A value of an expression can be assigned only to a variable of the same type.

    Otherwise the type cast is necessary.
  - Example of the implicit type cast.

```
int i = 320.4; // implicit conversion from 'double' to 'int' changes value from
   320.4 to 320 [-Wliteral-conversion]
char c = i;    // implicit truncation 320 -> 64
```

- C is type safe only within a limited context of the compilation, e.g., for `printf("%d\n", 10.1);` a compiler reports an error.
- In general, C is not type safe. *In runtime, it is possible to write out of the allocated memory space.*

Compound Assignment

- A short version of the assignment to compute a new value of the variable from itself:

  ⟨variable⟩ = ⟨variable⟩ ⟨operator⟩ ⟨expression⟩

- can be written as

  ⟨variable⟩ ⟨operator⟩ = ⟨expression⟩

Example

```
int i = 10;
double j = 12.6;

i = i + 1;
j = j / 0.2;
```

```
int i = 10;
double j = 12.6;

i += 1;
j /= 0.2;
```

- Note that the assignment is an expression.

  The assignment of the value to the variable is a side effect.

```
int x, y;

x = 6;
y = x = x + 6;
```


Assignment Expression and Assignment Statement

- The statement performs some action and it is terminated by ;

```
robot_heading = -10.23;
robot_heading = fabs(robot_heading);
printf("Robot heading: %f\n", robot_heading);
```

- Expression has **type and value**.

23	int type, value is 23
14+16/2	int type, value is 22
y=8	int type, value is 8

- Assignment is an expression and its value is assigned to the left side.
- The assignment expression becomes the assignment statement by adding **the semicolon**.

Undefined Behaviour

- There are some statements that can cause **undefined behavior** according to the C standard.
  - `c = (b = a + 2) - (b - 1);`
  - `j = i * i++;`
- The program may behaves differently according to the used compiler, but may also not compile or may not run; or it may even crash and behave erratically or produce meaningless results.
- It may also happened if variables are used without initialization.

- Avoid statements that may produce undefined behavior!

  A further detailed example of undefined behavior and code optimization with its analysis is in Lecture 09.

Part II

Part 2 – Control Structures: Selection Statements and Loops

Statement and Compound Statement (Block)

- Statement is terminated by ;

  Statement consisting only of the semicolon is empty statement.

- Block consists of sequences of declarations and statements.
- **ANSI C, C89, C90**: Declarations must be placed prior other statements.

  It is not necessary for C99.

- Start and end of the block is marked by the curly brackets { and }.
- A block can be inside other block.

```c
void function(void)
{ /* function block start */
   {/* inner block */
      for (i = 0; i < 10; ++i)
      {
      //inner for-loop block
      }
   }
}
```

```c
void function(void) { /* function block start */
   { /* inner block */
      for (int i = 0; i < 10; ++i) {
      //inner for-loop block
      }
   }
}
```

Notice the coding styles.

Coding Style

- It supports clarity and readability of the source code.

  https://www.gnu.org/prep/standards/html_node/Writing-C.html

- Formatting of the code is the fundamental step.

  Setup automatic formatting in your text editor.

- Appropriate identifiers.
- Train yourself in coding style even at the cost of slower coding!
- Readability and clarity is important, especially during debugging!

  Notice, sometimes it can be better to start from scratch

- Recommend coding style.

```c
void function(void)
{ /* function block start */
   for (int i = 0; i < 10; ++i) {
      //inner for-loop block
      if (i == 5) {
         break;
      }
   }
}
```

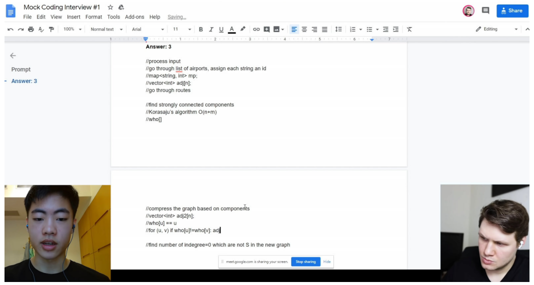
- Use English, especially for identifiers.
- Use nouns for variables.
- Use verbs for function names.

Lecturer's preference: indent shift 3, space characters rather than tabular.

Coding Style – Code Clarity and Readability

- There are many different coding styles.
- Inspire yourself by existing recommendations and by reading representative source codes.

Clean Code - Uncle Bob / Lesson 1
https://youtu.be/7EmboKQH8lM



Google Coding Interview with a High School Student
https://youtu.be/qz9tKlF431k

http://users.ece.cmu.edu/~eno/coding/CCodingStandard.html;
https://www.doc.ic.ac.uk/lab/cplus/cstyle.html;
http://en.wikipedia.org/wiki/Indent_style;
https://google.github.io/styleguide/cppguide.html;
https://www.kernel.org/doc/Documentation/process/coding-style.rst

Compound Command and Nesting 1/2

Four nested levels.

```c
int get_sum_of_even_numbers(int from, int to)
{
   if (from < to) {
      int sum = 0;
      for (int number = from; number <= to; ++number) {
         if (number % 2 == 0) {
            sum += number;
         }
      } // end for loop
      return sum;
   } else {
      return 0;
   }
}
```

We aim to have a more readable form.

```c
int get_sum_of_even_numbers(int from, int to)
{
   if (from > to) return 0;
   int sum = 0;
   for (int number = from; number <= to; ++number) {
      sum += filter_odd(number);
   } // end for loop
   return sum;
}
```

Extraction (new function definition).

```c
int filter_odd(int number);

int get_sum_of_even_numbers(int from, int to)
{
   if (from < to) {
      int sum = 0;
      for (int number = from; number <= to; ++number) {
         sum += filter_odd(number);
      } // end for loop
      return sum;
   } else {
      return 0;
   }
}

int filter_odd(int number)
{
   if (number % 2 == 0) {
      return number;
   }
   return 0;
}
```

- Using extraction and inversion techniques, we reduce the nesting depth.

https://youtu.be/CFRhGnuXG-4

Compound Command and Nesting 2/2

Inversion (substitution of the input value conditions).

```c
int filter_odd(int number);

int get_sum_of_even_numbers(int from, int to)
{
   if (from > to) {
      return 0;
   }
   int sum = 0;
   for (int number = from; number <= to; ++number) {
      sum += filter_odd(number);
   } // end for loop
   return sum;
}

int filter_odd(int number)
{
   if (number % 2 == 0) {
      return number;
   }
   return 0;
}
```

Final cleanup.

```c
int filter_odd(int number);

int get_sum_of_even_numbers(int from, int to)
{
   if (from > to) return 0;

   int sum = 0;
   for (int number = from; number <= to; ++number) {
      sum += filter_odd(number);
   } // end for loop
   return sum;
}

int filter_odd(int number)
{
   return (number % 2 == 0) : number : 0;
}
```

- By using the techniques of extraction and inversion we reduce the nesting depth.

https://youtu.be/CFRhGnuXG-4

Control Statements

- Selection Statement
  - Selection Statement: `if ()` or `if () ... else`
  - Switch Statement: `switch () case ...`
- Control Loops
  - `for ()`
  - `while ()`
  - `do ... while ()`
- Jump statements (unconditional program branching)
  - `continue`
  - `break`
  - `return`
  - `goto`

Selection Statement – if

- `if (expression) statement`$_1$`; else statement`$_2$
- For `expression != 0` the `statement`$_1$ is executed; otherwise `statement`$_2$.

  The statement can be the compound statement.
- The `else` part is optional.
- Selection statements can be nested and cascaded.

Why You Shouldn't Nest Your Code – https://youtu.be/CFRhGnuXG-4.

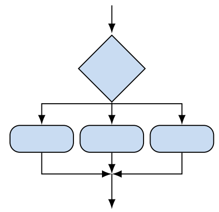
```c
int max;
if (a > b) {
   if (a > c) {
      max = a;
   }
}
```

```c
int max;
if (a > b) {
   ...
} else if (a < c) {
   ...
} else if (a == b) {
   ...
} else {
   ...
}
```


The switch Statement

- Allows to branch the program based on the value of the expression of the enumerate (integer) type, e.g., **int**, **char**, **short**, **enum**.
- The form is

```
switch (expression) {
   case constant_1: statements_1; break;
   case constant_2: statements_2; break;
   ...
   case constant_n: statements_n; break;
   default: statements_def; break;
}
```



where *constants* are of the same type as the *expression* and *statements$_i$* is a list of statements.

- Switch statements can be nested.

  Semantics: First the expression value is calculated. Then, the statements under the same value are executed. If none of the branch is selected, statements$_{def}$ under `default` branch as performed (optional).

The switch Statement – Example

```
switch (v) {
   case 'A':
      printf("Upper 'A'\n");
      break;
   case 'a':
      printf("Lower 'a'\n");
      break;
   default:
      printf(
      "It is not 'A' nor 'a'\n");
      break;
}
```

```
if (v == 'A') {
   printf("Upper 'A'\n");
} else if (v == 'a') {
   printf("Lower 'a'\n");
} else {
   printf(
   "It is not 'A' nor 'a'\n");
}
```

lec02/switch.c

The Role of the break Statement

- The statement **break** terminates the branch. If not presented, the execution continues with the statement of the next `case` label.

Example

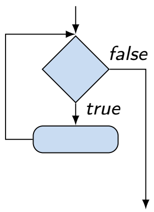
```
int part = ?
switch(part) {
   case 1:
      printf("Branch 1\n");
      break;
   case 2:
      printf("Branch 2\n");
   case 3:
      printf("Branch 3\n");
      break;
   case 4:
      printf("Branch 4\n");
      break;
   default:
      printf("Default branch\n");
      break;
}
```

- part ← 1
  Branch 1
- part ← 2
  Branch 2
  Branch 3
- part ← 3
  Branch 3
- part ← 4
  Branch 4
- part ← 5
  Default branch

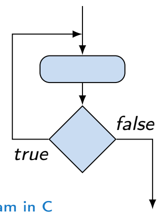
lec02/demo-switch_break.c

Loops

- The **for** and **while** loop statements test the controlling expression before the enter to the loop body.
  - **for** – initialization, condition, change of the controlling variable can be a part of the syntax.
    ```
    for (int i = 0; i < 5; ++i) {
       ...
    }
    ```
  - **while** – controlling variable out of the syntax
    ```
    int i = 0;
    while (i < 5) {
       ...
       i += 1;
    }
    ```



- The **do** loop tests the controlling expression after the first loop is performed.
  ```
  int i = -1;
  do {
     ...
     i += 1;
  } while (i < 5);
  ```



The **for** Loop

- The basic form has four parts (three expressions and a single statement).

  `for (expr1; expr2; expr3) statement`

- All $expr_i$ are expressions and typically they are used for
  1. $expr_1$ – initialization of the controlling variable (side effect of the assignment expression);
  2. $expr_2$ – Test of the controlling expression;
  3. If $expr_2$ `!=0` the `statement` is executed; Otherwise the loop is terminated.
  4. $expr_3$ – updated of the controlling variable (performed at the end of the loop
- Any of the expressions $expr_i$ can be omitted.
- **break** statement – force termination of the loop.
- **continue** – force end of the current iteration of the loop.

  The expression $expr_3$ is evaluated and test of the loop is performed.
- An infinity loop can be written by omitting the expressions.

  `for (;;) {...}`

The continue Statement

- It transfers the control to the evaluation of the controlling expression.
- The `continue` statement can be used inside the body of the loops.
  - `for ()`
  - `while ()`
  - `do...while ()`
- Examples

```c
int i;
for (i = 0; i < 20; ++i) {
   if (i % 2 == 0) {
      continue;
   }
   printf("%d\n", i);
}
```

lec02/continue.c

```c
for (int i = 0; i < 10; ++i) {
   printf("i: %i ", i);
   if (i % 3 != 0) {
      continue;
   }
   printf("\n");
}
```

lec02/demo-continue.c

```
clang demo-continue.c
./a.out
i:0
i:1 i:2 i:3
i:4 i:5 i:6
i:7 i:8 i:9
```


The break Statement – Force Termination of the Loop

- The program continue with the next statement after the loop.
- Example in the `while` loop.

```c
int i = 10;
while (i > 0) {
   if (i == 5) {
      printf("i reaches 5, leave the loop\n");
      break;
   }
   i--;
   printf("End of the while loop i: %d\n", i);
}
```

lec02/break.c

- Example in the `for` loop.

```c
for (int i = 0; i < 10; ++i) {
   printf("i: %i ", i);
   if (i % 3 != 0) {
      continue;
   }
   printf("\n");
   if (i > 5) {
      break;
   }
}
```

```
clang demo-break.c
./a.out
i:0
i:1 i:2 i:3
i:4 i:5 i:6
```

lec02/demo-break.c

The goto Statement

- `goto` allows transfing the control to the defined label.

It can be used only within a function body.

- Syntax `goto label;`.
- The jump `goto` can jump only outside of the particular block, it can jump to a statement.
- It can be used only within a function block.

```c
int test = 3;
for (int i = 0; i < 3; ++i) {
   for (int j = 0; j < 5; ++j) {
      if (j == test) {
         goto loop_out;
      }
      fprintf(stdout, "Loop i: %d j: %d\n", i, j);
   }
}
return 0;
loop_out:
fprintf(stdout, "After loop\n"); // goto can jump to a label that
    represents statement (there must be an address to be jump at).
return -1;
```

lec02/goto.c

Nested Loops

- The **break** statement terminates the inner loop.

```c
for (int i = 0; i < 3; ++i) {
   for (int j = 0; j < 3; ++j) {
      printf("i-j: %i-%i\n", i, j);
      if (j == 1) {
         break;
      }
   }
}
```

```
i-j: 0-0
i-j: 0-1
i-j: 1-0
i-j: 1-1
i-j: 2-0
i-j: 2-1
```

- The outer loop can be terminated by the `goto` statement.

```c
for (int i = 0; i < 5; ++i) {
   for (int j = 0; j < 3; ++i) {
      printf("i-j: %i-%i\n", i, j);
      if (j == 2) {
         goto outer;
      }
   }
}
outer:
```

```
i-j: 0-0
i-j: 0-1
i-j: 0-2
```

lec02/demo-goto.c

Example – isPrimeNumber() 1/2

```
#include <stdbool.h>
#include <math.h>

_Bool isPrimeNumber(int n)
{
   _Bool ret = true;
   for (int i = 2; i <= (int)sqrt((double)n); ++i) {
      if (n % i == 0) {
         ret = false;
         break;
      }
   }
   return ret;
}
```

lec02/demo-prime.c

- Once the first factor is found, call `break` to terminate the loop.

It is not necessary to test other numbers.

Example – isPrimeNumber() 2/2

- The value of `(int)sqrt((double)n)` is not changing in the loop.

```
for (int i = 2; i <= (int)sqrt((double)n); ++i) {
   ...
}
```

- We can use the comma operator to initialize the `maxBound` variable.

```
for (int i = 2, maxBound = (int)sqrt((double)n);
      i <= maxBound; ++i) {
   ...
```

- Or, we can declare `maxBound` as a constant variable.

```
_Bool ret = true;
const int maxBound = (int)sqrt((double)n);
for (int i = 2; i <= maxBound ; ++i) {
   ...
}
```

E.g., Compile and run `demo-prime.c`: `clang demo-prime.c -lm; ./a.out 13`.

Conditional Expression – Example Greatest Common Divisor

```
int getGreatestCommonDivisor(int x, int y)
{
   int d;
   if (x < y) {
      d = x;
   } else {
      d = y;
   }
   while ( (x % d != 0) || (y % d ! = 0)) {
      d = d - 1;
   }
   return d;
}
```

- The same with the conditional expression $expr_1$? $expr_2$: $expr_3$ can be as follows.

```
int getGreatestCommonDivisor(int x, int y)
{
   int d = x < y ? x : y;
   while ( (x % d != 0) || (y % d ! = 0)) {
      d = d - 1;
   }
   return d;
}
```

lec02/demo-gcd.c

Part III

Part 3 – Assignment HW 01

HW 01 – Assignment

Topic: **ASCII art**

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

- **Motivation**: Have a fun with loops and user parametrization of the program.
- **Goal**: Acquire experience using loops and inner loops.
- **Assignment** https://cw.fel.cvut.cz/wiki/courses/b3b36prg/hw/hw01
  - Read parameters specifying a picture of small house using selected ASCII chars.
    https://en.wikipedia.org/wiki/ASCII_art
  - Assesment of the input values.
- Deadline: 16.03.2024, 23:59 AoE.

AoE – Anywhere on Earth.

Part IV

Part 4 – Coding Example (optional)

Coding Example – Assignment

- Implement a program that prints the pattern with seven lines.
- The default width n is 27 characters or it is read as the first program argument (if given).
- The width n needs to be odd number, or the program returns **100**.
- It holds $11 \le n \le 67$, or the program returns **101**.
- On success, the program prints seven lines and returns 0.
- Avoid "magic numbers" in the program whenever is it possible.

```
* * * * * * * * * * * * * * * * * *
** ** ** ** ** ** ** ** ** ** ** **
*** *** *** *** *** *** *** *** ***
***********************************
*** *** *** *** *** *** *** *** ***
** ** ** ** ** ** ** ** ** ** ** **
* * * * * * * * * * * * * * * * * *
```

- Convert program `argv[1]` by `atoi()`, if given.
- Decompose the program into printing 7× line.
- Implement the program infrastructure first.
- Then, focus on logic to particular lines controlled by a suitably designed **expressions**.

Coding Example – Implementation Strategy 1/4

- Define return (error) values to make the code clean (0, 100, 101), e.g., using `enum`.
- Define valid range $\langle 11, 67 \rangle$, e.g., using `#define`.
- Ensure accessing passed arguments to the program only if they are passed to the program.
- Ensure the number of lines n is a valid value or set the error program return value.
- Peform any operation only if arguments (values) are valid.
- Split printing 7 lines into two for loops, with one print line call between the loops.
- Implement a function to print the line pattern.

```c
#include <stdio.h> //for putchar()
#include <stdlib.h> //for atoi()

enum {
   ERROR_OK = 0,
   ERROR_INPUT = 100,
   ERROR_RANGE = 101
};

#define MIN_VALUE 11
#define MAX_VALUE 67

#define LINES 3

// Print line of the with n using character
    in c and space; with k continuous
    characters c followed by space.
void print(char c, int n, int k);
```

Coding Example – Implementation Strategy 2/4

- Define return (error) values to make the code clean (0, 100, 101), e.g., using enum.
- Define valid range $\langle 11, 67\rangle$, e.g., using #define.
- Ensure accessing passed arguments to the program only if they are passed to the program.
- Ensure the number of lines *n* is a valid value or set the error program return value.
- Peform any operation only if arguments (values) are valid.
- Split printing 7 lines into two for loops, with one print line call between the loops.
- Implement a function to print the line pattern.

```c
...
int main(int argc, char *argv[])
{
   int ret = ERROR_OK;
   int n = argc > 1 ? atoi(argv[1]) : 27; // convert argv[1] or use default value

   ret = n % 2 == 0 ? ERROR_INPUT : ret; // ensure n is odd number
   if (!ret &&
         (n < MIN_VALUE || n > MAX_VALUE)) {
      ret = ERROR_RANGE; //ensure n is in the closed interval [MIN_VALUE, MAX_VALUE]
   }
   ...
   return ret;
}
```


Coding Example – Implementation Strategy 3/4

- Define return (error) values to make the code clean (0, 100, 101), e.g., using enum.
- Define valid range $\langle 11, 67\rangle$, e.g., using #define.
- Ensure accessing passed arguments to the program only if they are passed to the program.
- Ensure the number of lines *n* is a valid value or set the error program return value.
- Peform any operation only if arguments (values) are valid.
- Split printing 7 lines into two for loops, with one print line call between the loops.
- Implement a function to print the line pattern.

```c
// print a line with n characters with the
   pattern:  k-times c, then space.
// the line ends by new line character '\n'.
void print(char c, int n, int k);

int main(int argc, char *argv[])
{ ...
   if (!ret) { // only if ret == ERROR_OK
      for (int l = 1; l <= LINES; ++l) {
         print('*', n, l); // print l x '*'
      }
      print('*', n, n); // print n x '*'
      for (int l = LINES; l > 0 ; --l) {
         print('*', n, l); // print l x 'x'
      }
   }
   return ret;
}
```


Coding Example – Implementation Strategy 4/4

- Define return (error) values to make the code clean (0, 100, 101), e.g., using enum.
- Define valid range $\langle 11, 67\rangle$, e.g., using #define.
- Ensure accessing passed arguments to the program only if they are passed to the program.
- Ensure the number of lines *n* is a valid value or set the error program return value.
- Peform any operation only if arguments (values) are valid.
- Split printing 7 lines into two for loops, with one print line call between the loops.
- Implement a function to print the line pattern.

```c
void print(char c, int n, int k)
{
   for (int i = 0; i < n; ++i) {
      putchar( (i+1) % (k+1) ? c : ' ');
   }
   putchar('\n');
}
```

- The line consists of `n` characters; so *n* characters has to be printed.
- Space is placed after each `k` characters of `c`.
- Multiple of `k` can be detected by the remainder after division, the operator `%`.
- We need to handle `i` starts from 0.
- The space is every (`k+1`)-th character.

Coding Example – Implementation Strategy 4(b)/4

- Define return (error) values to make the code clean (0, 100, 101), e.g., using enum.
- Define valid range $\langle 11, 67\rangle$, e.g., using #define.
- Ensure accessing passed arguments to the program only if they are passed to the program.
- Ensure the number of lines *n* is a valid value or set the error program return value.
- Peform any operation only if arguments (values) are valid.
- Split printing 7 lines into two for loops, with one print line call between the loops.
- Implement a function to print the line pattern.

```c
void print(char c, int n, int k)
{
   int i, j;
   for (i = j = 0; i < n; ++i, ++j) {
      if (j == k) {
         putchar(' ');
         j = 0;
      } else {
         putchar(c);
      }
   }
   putchar('\n');
}
```

- Use extra counter `j` for space as every `k`-th printed character.
- Enjoy comma operator to increment `j` within the **for** loop.

Summary of the Lecture

Topics Discussed

- Expressions
  - Operators – Arithmetic, Relational, Logical, Bitwise, and others
  - Operator Associativity and Precedence
  - Assignment and Compound Assignment
  - Implementation-Defined Behaviour
  - Undefined Behaviour
- Coding Styles
- Select Statements
- Loops
- Conditional Expression

- Next: Data types, memory storage classes, function call