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

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Lecture 02

B3B36PRG – C Programming Language

Overview of the Lecture

- Part 1 – Expressions
  - Operators – Arithmetic, Relational, Logical, Bitwise, and Other
  - 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 02

Part I

Part 1 – Expressions

Outline

- Operators – Arithmetic, Relational, Logical, Bitwise, and Other
- Associativity and Precedence
- Assignment

Expressions

- **Expression** – prescribes calculation using *operands*, *operators*, and *brackets*
- Expression consists 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

- A particular order of evaluation can be precisely prescribed by **fully parenthesized expression**

Simply: If you are not sure, use brackets.

Operators

- Operators are selected characters (or a 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, ...)
  - **Logical** operators – logical `AND` and `OR`
  - **Bitwise** operators – bitwise `AND`, `OR`, `XOR`, bitwise shift (left, right)
  - Assignment operator **=** – a variable (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: $\sim$
- Ternary operator – conditional expression **? :**

Reminder

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, i.e., compiler, environment, computer architecture

  E.g., Reminder behavior for negative values and version of the C prior C99.
- The reason for that is to the focus of C on efficiency, i.e., match the hardware behavior

- Having this in mind, it is best to rather avoid writing programs that depends on implementation-defined behavior.

  K.N.King: Page 55

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**	

Notice, 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.

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)
ˆ	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 about y bits to the left
>>	Bitwise right shift	`x >> y`	Shift of x about 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 it 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 surprise – parenthesized the expression!

Example – Bitwise Expressions

```
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
- The access is realized through a pointer

It allows great options, but it also needs responsibility.

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.

*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.

Outline

- Operators – Arithmetic, Relational, Logical, Bitwise, and Other
- Associativity and Precedence
- Assignment

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 left-associative

  E.g., y=y+8

  First, the whole right side of the operator = is evaluated and then, the results is 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	ˆ		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	=	R→L	Assignment
	+=, -=		additive
	*=, /=, %=		multiplicative
	<<=, >>=		bitwise shift
	&=, ^=, |=		Bitwise AND, XOR, OR
15	,	L→R	Comma

K. N. King: Page 735
http://en.cppreference.com/w/c/language/operator_precedence

Outline

- Operators – Arithmetic, Relational, Logical, Bitwise, and Other
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- Assignment

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

  $$\langle \textbf{variable} \rangle = \langle \textbf{expression} \rangle$$

  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 type case it necessary
  - Example of implicit type case

```
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:

  $\langle$**variable**$\rangle$ = $\langle$**variable**$\rangle$ $\langle$**operator**$\rangle$ $\langle$**expression**$\rangle$

- can be written as

  $\langle$**variable**$\rangle$ $\langle$**operator**$\rangle$ = $\langle$**expression**$\rangle$

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;
```

- Notice, 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;
```

Compound Assignment

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

$$\langle \text{variable} \rangle = \langle \text{variable} \rangle \ \langle \textbf{operator} \rangle \ \langle \text{expression} \rangle$$

- can be written as

$$\langle \text{variable} \rangle \ \langle \textbf{operator} \rangle = \langle \text{expression} \rangle$$

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;
```

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

Example of Undefined Behaviour

- Standard C does not defined the behaviour for the overflow of the integer value (`signed`)
  - E.g., For the complement representation the expression can be `127 + 1` of the `char` equal to `-128` (see `lec02/demo-loop_byte.c`)
  - Representation of integer values may depend on the architecture and can be different, e.g., binary or inverse codes
- Implementation of the defined behaviour can be computationally expensive, and thus the behaviour is not defined by the standard
- Behaviour is not defined and depends on the compiler, e.g. `clang` and `gcc` without/with the optimization `-O2`
  - ```
    for (int i = 2147483640; i >= 0; ++i) {
       printf("%i %x\n", i, i);
    }
    ```
    `lec02/int_overflow-1.c`

    Without the optimization, the program prints 8 lines, for `-O2`, the program compiled by `clang` prints 9 lines and `gcc` produces infinite loop.
  - ```
    for (int i = 2147483640; i >= 0; i += 4) {
       printf("%i %x\n", i, i);
    }
    ```
    `lec02/int_overflow-2.c`

    A program compiled by `gcc` with `-O2` is crashing

Take a look to the asm code using the compiler parameter `-S`

Part II

Part 2 – Control Structures: Selection Statements and Loops

Outline

- Statements and Coding Styles
- Selection Statements
- Loops
- Conditional Expression

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 { and }
- A block can be inside other block

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

```
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 (PRG)

```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 Styles – Links

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

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/CodingStyle

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https://google.github.io/styleguide/cppguide.html

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`

Outline

- Statements and Coding Styles
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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

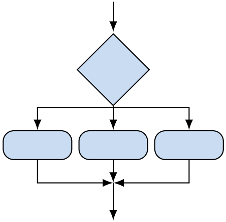
```
int max;
if (a > b) {
   if (a > c) {
      max = a;
   }
}
```

```
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

```c
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 $\leftarrow$ 1
  Branch 1
- part $\leftarrow$ 2
  Branch 2
  Branch 3
- part $\leftarrow$ 3
  Branch 3
- part $\leftarrow$ 4
  Branch 4
- part $\leftarrow$ 5
  Default branch

lec02/demo-switch_break.c

Outline

- Statements and Coding Styles
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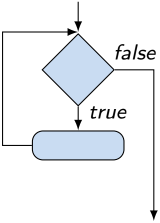
Loops

- Loop statements **for** and **while** 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

```c
for (int i = 0; i < 5; ++i) {
   ...
}
```

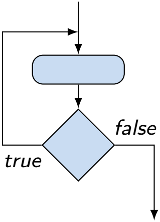
  - **while** – controlling variable out of the syntax

```c
int i = 0;
while (i < 5) {
   ...
   i += 1;
}
```



- The **do** loop tests the controlling expression after the first loop

```c
int i = -1;
do {
   ...
   i += 1;
} while (i < 5);
```



The **for** Loop

- The basic form is: for (expr$_1$; expr$_2$; expr$_3$) statement
- All expr$_i$ are expression 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 expressions of the loops
- 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

```
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

```
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

- Allows to transfers 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
- 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");
return -1;
```

lec02/goto.c

Nested Loops

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

```
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;
      }
   }
}
```

- The outer loop can be terminated by the goto statement

```
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:
```

lec02/demo-goto.c

Nested Loops

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

```
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

```
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:
```

lec02/demo-goto.c

Nested Loops

- The break statement terminates the inner loop

```
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

```
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:
```

lec02/demo-goto.c

Nested Loops

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

```
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

```
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 constant

```
_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

Outline

- Statements and Coding Styles
- Selection Statements
- Loops
- Conditional Expression

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: $expr_1$? $expr_2$: $expr_3$

```
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

Conditional Expression – Example Greatest Common Divisor

```c
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: $expr_1$? $expr_2$: $expr_3$

```c
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 02

HW 02 – Assignment

Topic: **Prime Factorization**

Mandatory: **3 points**; Optional: **5 points**; Bonus : none

- **Motivation**: Experience loops, variables and their internal representation in a computational task
- **Goal**: Familiar yourself with the algorithmic solution of the computational task
- **Assignment**:

  https://cw.fel.cvut.cz/wiki/courses/b3b36prg/hw/hw02

  - Read sequence of positive integer values, less than 10^8, but still representable as 64-bit integer, and compute their prime factorization using Sieve of Eratosthenes

    https://en.wikipedia.org/wiki/Sieve_of_Eratosthenes
  - Optional assignment – an extension of the prime factorization for integer values with up to 100 digits. Notice, the input values are such that, the the greatest number in the factorization is always less than 10^6.
- **Deadline**: 11.03.2017, 23:59:59 PST

PST – Pacific Standard Time

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

Topics Discussed

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