

Advanced Programming in C++

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```
#include <iostream>
#include <vector>
#include <string>

using namespace std;

int main() {
    vector<string> msg {"Welcome", "to", "advanced", "C++!"};
    for (const string& word : msg) { // C++11 standard
        cout << word << " ";
    }
    cout << endl;
}
```

Week 1

- 1. Designing and running programs
- 2. Variables, Types, Constants
- 3. Basic statements: if, switch, loops

Week 2

- 4. Functions, Recursion, Call by Value
- 5. Arrays, Multidimensional Arrays

Week 3

- 6. Objects and Classes, Attributes and Methods

Week 4

- 7. Pointers and Memory Allocation

Week 5

- 8. Inheritance and Polymorphism

Week 6

- 9. Handling of Exceptions

Week 7

- 10. Container Classes
- 11. Templates and STL

In this course, you learn advanced themes in C++ programming

The course consists of:

- Lecture: 2h per week, basic concepts
- Lab: 2h per week, getting / correcting programming tasks
- Homework: \pm 2h per week, solving assignments



Links to lecture slides and assignments are available on moodle:

- <https://moodle.uni-siegen.de/course/view.php?id=34345>
- updates to the slides will be made available during the term

We learn C++ by doing, hence: *follow lectures and exercises*

Disclaimer:

This course's material was inspired by similar course from Prof. Roland Wismueller (Uni Siegen) and Prof. Hannah Bast (Uni Freiburg)

50% of your grade comes from:

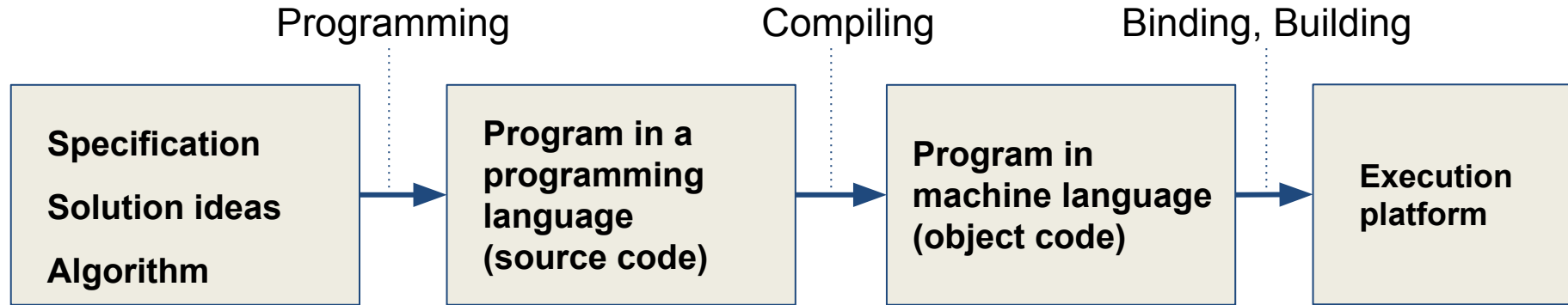
- Set of programming assignments during term and programming on paper
- These need to be delivered in-class
=> your presence is required in these sessions

50% of your grade comes from the 1-hour written exam:

- 1 handwritten A4 (double-sided) page is allowed
- Bring a photo ID, your student ID and a pen (blue/black ink only)
- Structure: Programming tasks *very similar* to the exercises

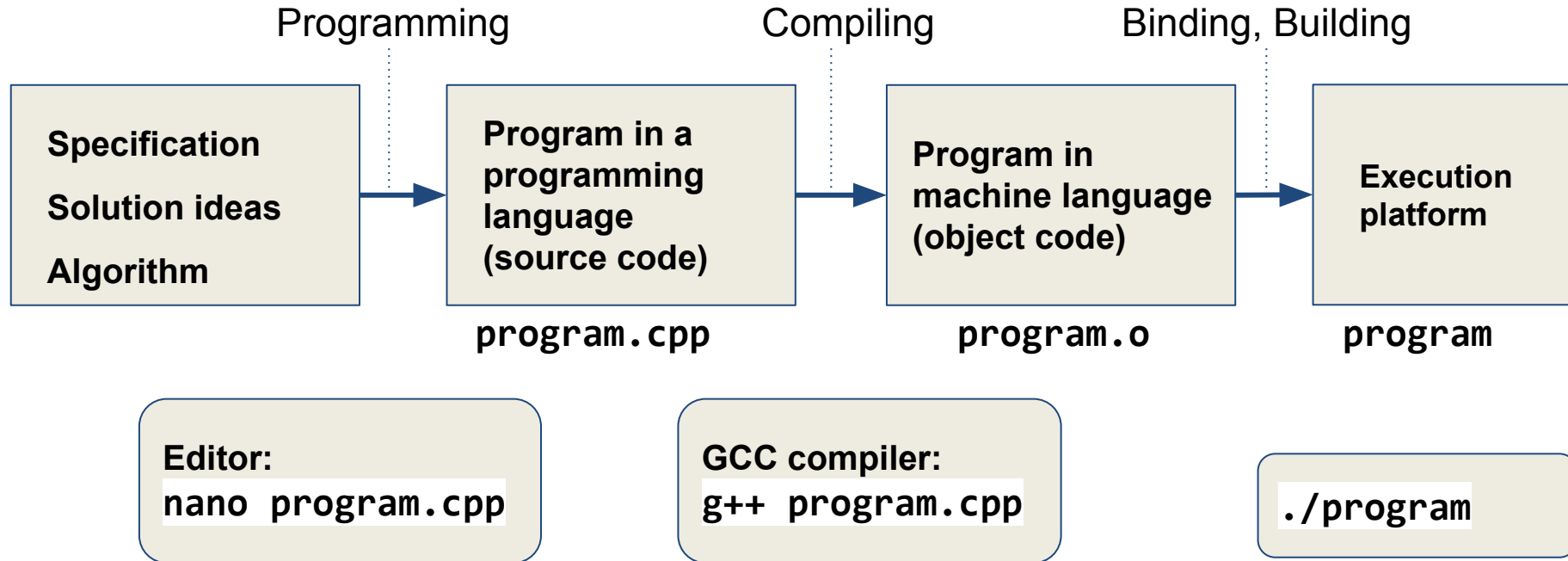
1. Designing programs

Steps in creating a program:



1. Designing programs

Steps in creating a program:



1.1. Program structure:

- A program is essentially a series of *machine instructions* that tell the system what to do, step by step, similar to a recipe
- Source code allows humans to formulate instructions in an understandable fashion, which then can be translated to machine instructions → In this course, we use C++ to create source code
 - C++ source code files are text files that end with **.cpp** or **.h**
 - A *compiler* then translates these to a program that consists out of machine instructions
- Creating source code needs a file system and operating system

1. Designing programs

1.2. Using GitHub Repository, g++, editors

We will use a github repository: <https://github.com/kristofvl/AdvancedCPP> as a code base for the slides, all exercises, and home works from the lecture

- You will need a github account
- It allows keep track of changes, and distributing larger projects

We'll use [GNU g++](#). For Linux or macOS, you can directly use g++
In Windows, you can install Windows Subsystem for Linux (WSL), to have a Linux environment to use g++ inside it

1. Designing programs

1.2. Using GitHub Repository, g++, editors

You are free in the use of editor. Here are a few options:

[Microsoft Visual Studio Code \(VSCode\)](#) , [Sublime](#) , [Lapce](#), [Zed](#)

Text-based coding editors: Vim, Emacs, [NeoVim](#), [Helix](#)

Not suggested: Notepad, Gedit, and other similar editors

1. Designing programs

```
/* The Birthday Paradox -- an illustration
   Author: kvl,   Date: first week   */
```

BDay.cpp

1. Every program should mention who programmed it

2. Every program needs a function "main" that contains all code to be executed

3. The function "main" will exit and send a number (usually zero, for "no error") to the operating system

```
int main() {
```

```
    return 0;
}
```

1. Designing programs

BDay.cpp

```
/* The Birthday Paradox -- an illustration
   Author: kv1,   Date: first week   */
#include <iostream>

class BDay {
    /* p(x) --> probability of x happening,  p(x) = 1 - p(not x)
       p(2 persons have same birthday) = 1 - (365-1)/365 * (365-2)/365 * ... * (365 - (n-1))/365 */
public:
    double prob(int n);
};

double BDay::prob(int n) {
    double p = 1.0;    // probability that out of n people, 2 have the same birthday
    for (int i = 0; i < n; i++) {    // i = 1, 2, ..., n-1
        p = p * (365-i)/365;
    }
    return 1 - p;
}

int main() {
    int n = 23;
    BDayP b;    // create an object to access the prob() method:
    std::cout << "The chance that 2 out of " << n << " people have a same birthday is " << b.prob(n);
    return 0;
}
```

1. Designing programs

1.3. Compiling and building a program:

- Type `g++` to launch the GCC c++ compiler: `g++ BDay.cpp`
 - `g++` creates the program, a file with the default name `a.out` in the current directory, which can be executed in the terminal: `./a.out`
- Add `-o` to specify another name: `g++ BDay.cpp -o BDay`
 - `g++` creates the file `BDay`, which can be executed: `./BDay`
- The compiler tries to compile all other needed source files and needs a `main` function in the files that specifies what your program does
 - `g++` can compile multiple files, e.g.: `g++ ex1.cpp ex2.cpp`
 - `g++` can compile code for later use in a program with `-c`:
`g++ -c BDay.cpp`, which creates `BDay.o`
`g++ BDayx.o` then creates the program `a.out`

1. Designing programs

1.3. Compiling and building a program:

- Add `--std` to specify which C++ standard your code is for. If for instance you use features for C++11 you need to add `--std=c++11`:
`g++ BDay.cpp -o BDay --std=c++11`

Features you use may be in different standards, and you can specify them by the option `--std` to let the compiler compile the source code in different standards

1. Designing programs

1.4. Including libraries:

- The compiler can include others' code as a library that is mentioned in the source code (for example `#include <iostream>`)
 - In this course, we will see mostly such *standard* libraries, `g++` knows where to search for their files and links these:
`g++ BDaySimple.cpp`

```
/* The Birthday Paradox -- a simplification */
#include <iostream>
int main() {
    std::cout << "The chance that 2 out of 23 people have";
    std::cout << " a same birthday is about 0.5" << std::endl;
    return 0;
}
```

BDaySimple.cpp

1. Designing programs

1.4. Including libraries:

- The compiler can include others' code as a library that is mentioned in the source code (for example [ncurses](#): `#include <ncurses.h>`)
 - Other non-standard libraries need to be linked explicitly with `-l`:
`g++ BDayCentre.cpp -l ncurses`

```
/* The Birthday Paradox -- in the *middle* */
#include <ncurses.h> // draw text in terminal screen
int main() {
    initscr(); // initialize ncurses window
    mvaddstr(LINES/2, COLS/3, "The chance that 2 out of 23 have");
    mvaddstr(LINES/2+1, COLS/3, "the same birthday is about 0.5. wow.");
    getch(); // capture the user's pressed key
    endwin(); // close the ncurses window
    return 0;
}
```

BDayCentre.cpp

1.5. Indenting your code:

- To make everyone's code look the same, we recommend using [cpplint](#)
- We *also* recommend **2-space indentation** (see *all* examples in slideset):

```
void myFunction(bool exec, bool size) { // indent after each {
  int ret = 0;
  if (exec) { // indent after each {
    for (int i = 0; i < size; i++) { // indent after each {
      ret += i;
    } // de-indent before each }
  } else { // indent after each {
    ret = 12;
  } // de-indent before each }
} // de-indent before each }
```

2.1. The basic components of a program:

- Reserved keywords
- Preprocessor directives
- Names
- Constants
- Operators
- Braces
- Separators
- Comments

```
/* The Birthday Paradox -- in short */  
#include <iostream>  
int main() {  
    std::cout << "The chance that 2 out of";  
    std::cout << " 23 people have a same";  
    std::cout << " birthday is about ";  
    std::cout << 0.5 << std::endl;  
    return 0; // 0 back to operating system  
}
```

2.1.1. Reserved C++ keywords

Reserved keywords are words that are reserved for special meaning by the language standard and cannot be used as identifiers (names for variables, functions, classes, etc.). E.g.:

bool	do	namespace	switch
break	double	new	this
case	else	private	true
catch	false	protected	using
char	float	public	virtual
class	for	return	void
const	if	short	while
delete	int	sizeof	

2.1.2. Preprocessor directives

Source code can also contain so-called *preprocessor directives* that start with a `#` : We will use solely:

- `#include`, followed by a source file either:
 - surrounded by `<` and `>` , for example: `#include <ncurses.h>`
for source code from standard libraries
 - surrounded by `"` and `"` , for example: `#include "myCode"`
for source code in the current directory
- **header guards** to ensure that code is included only once:

```
#ifndef HEADERFILE
#define HEADERFILE

#endif
```

2.1.3. Names:

You can define names to variables, parameters, functions, etc.

- these names need to be unique (so no keywords)
- they can contain only letters, digits and underscores (`_`)
- they need to start with letters or an underscore
- their length is nearly unlimited
- examples:

correct	wrong	reason
Sum	get Name	no empty spaces
getName	Ver2-1	minus '-' not allowed
_all4you	2exp4	starts with a digit
__1_2	while	C++ keyword

2.1.4. Constants:

<code>15</code> (integer)	<code>3.14159f</code> (float)	<code>3.14159</code> (double)
<code>'p'</code> (character)	<code>"brb"</code> (string)	<code>true</code> (boolean)

2.1.5. Operators:

`+` `-` `*` `/` `&&` `||` `=` `==` `>=` `<=` `<<` `>>` `<` `>` ...

2.1.6. Braces:

`(` `)` `[` `]` `{` `}`

2.1.7. Separators:

`,` `;` `.` (space) as well as tabs or new lines

2.1.8. Comments:

- `// comment till the end of the line`
- `/* comment that spans across multiple lines */`
- note that a multi-line comment cannot contain `*/`:
`/* this example comment */ would cause an error */`

```
// probability that out of n people, 2

/* p(x) --> probability of x happening
   p(x) = 1 - p(not x)
   p(2 persons have same birthday) =
   ...*/

/** The Birthday Paradox -- illustration
 *   Author:   kv1
 *   Date:     last week
 */
```

IMPORTANT: Comments should explain your code but never be trivial

good: `int scrMaxWidth; // maximum screen width`

bad: `float aspectRatio; // this variable holds the aspect ratio`

2.1. Example:

```
/* An interactive example */  
#include <iostream>  
int main() {  
    char name[80]; // symbols array for the user's name  
    std::cout << "Hi, what's your name?" << std::endl;  
    std::cin >> name; // read the name from terminal  
    std::cout << "Welcome " << name;  
    if (name[0] == 'K') {  
        std::cout << ", I like your name!"  
    }  
    std::cout << std::endl;  
    return 0; // return a zero  
}
```

Annotations for the code example:

- comments
- preprocessor
- separators
- operators
- braces
- constants
- names
- keywords

2.2. Variables:

- represent *memory space*, where data of a certain type can be stored
- need to be declared and ideally initialized before use:

```
int keyPressCounter = 0; // how often did user press a key?
```

- have values that after declaration can be 'read out' and changed:

```
if (keyPressCounter > 27) // after 27 key presses,  
    keyPressCounter = 0; // we set it back to zero
```

- can't be changed afterwards, when declared (and initialized) as **constants**: `const int answer = 42; // after this, answer stays 42`
- live in a certain *scope*, typically the function in which it was declared. After this function ends, the variable is deleted from memory.

2.3. Data types: Integral

Native Type	Bytes	Range	Fixed width types <stdint.h>
bool	1	true, false	
char [†]	1	implementation defined	
signed char	1	-128 to 127	int8_t
unsigned char	1	0 to 255	uint8_t
short	2	-2^{15} to $2^{15}-1$	int16_t
unsigned short	2	0 to $2^{16}-1$	uint16_t
int	4	-2^{31} to $2^{31}-1$	int32_t
unsigned int	4	0 to $2^{32}-1$	uint32_t
long int	4/8		int32_t/int64_t
long unsigned int	4/8*		uint32_t/uint64_t
long long int	8	-2^{63} to $2^{63}-1$	int64_t
long long unsigned int	8	0 to $2^{64}-1$	uint64_t

2.3. Data types: Floating-Point

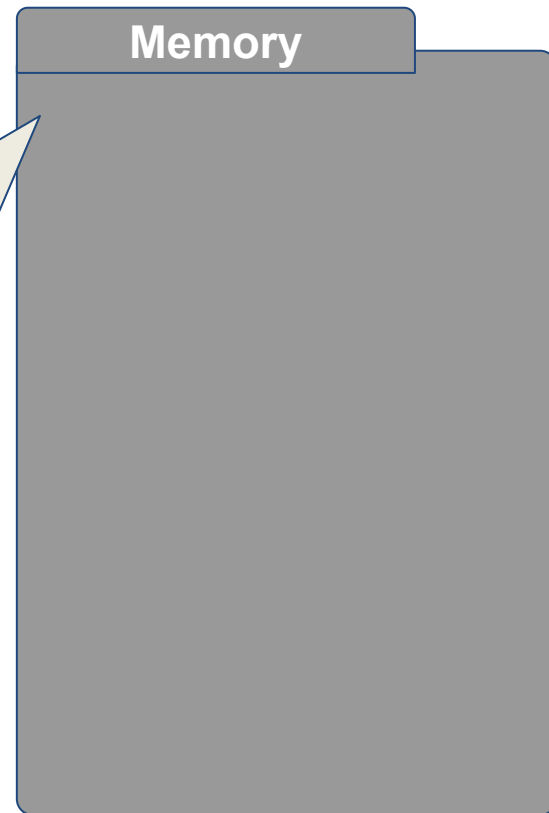
Native Type	IEEE	Bytes	Range	Fixed width types
				C++23 <code><stdfloat></code>
(bfloat16)	N	2	$\pm 1.18 \times 10^{-38}$ to $\pm 3.4 \times 10^{+38}$	<code>std::bfloat16_t</code>
(float16)	Y	2	0.00006 to 65,536	<code>std::float16_t</code>
float	Y	4	$\pm 1.18 \times 10^{-38}$ to $\pm 3.4 \times 10^{+38}$	<code>std::float32_t</code>
double	Y	8	$\pm 2.23 \times 10^{-308}$ to $\pm 1.8 \times 10^{+308}$	<code>std::float64_t</code>

2.3. Data types

- A type defines: what *values* the variable can have, how much memory is allocated for it, and which *operations* are possible
- All variables and constants have a type in C++
 - for constants, you can tell the type by their form
 - for variables, this is explicit in the declaration

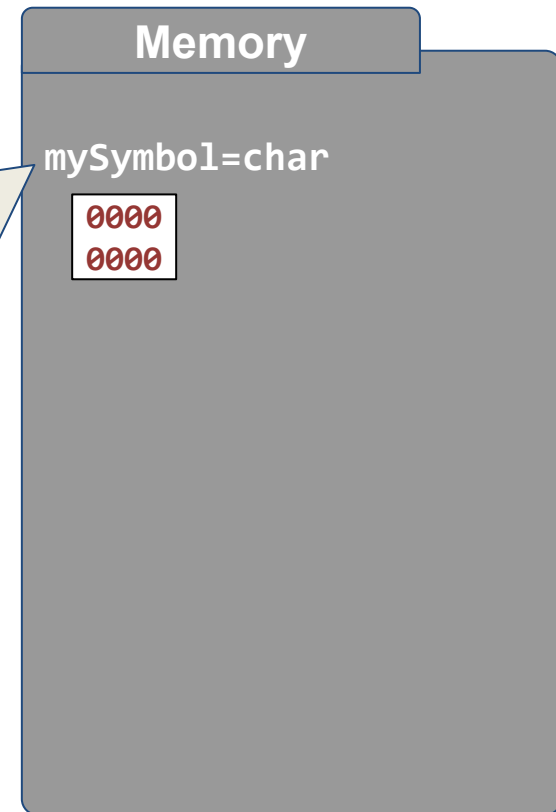
2.3. Data types: A (simplified) Memory View

```
/* reserving variables */  
int main() {  
    char mySymbol;    // store one character  
    int myInteger;    // store an integer  
    bool myBoolean;   // store a boolean  
    float myFloat;    // store a floating point  
    myInteger = 12;    // 12 = constant integer  
    myFloat = 12.0f;   // 12.0f = constant floating point  
    mySymbol = '@';    // '@' = constant character  
    myBoolean = true;  // true = constant boolean  
    return 0;  
}
```



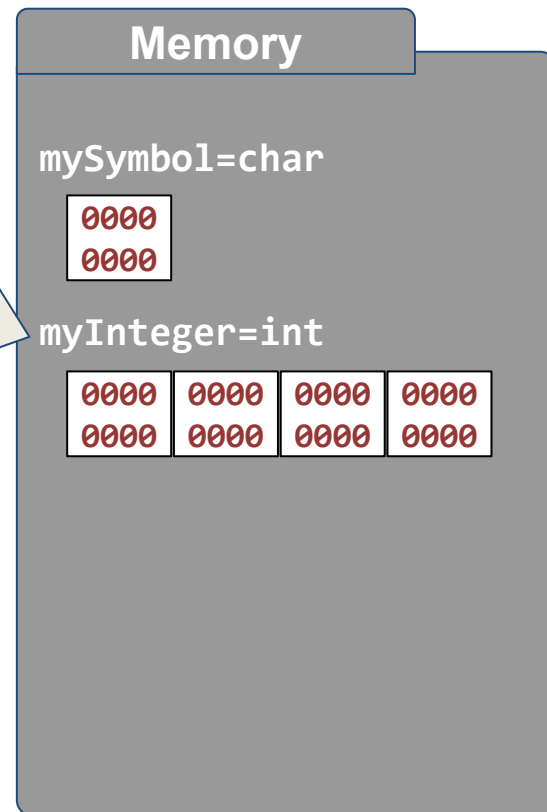
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    float myFloat;    // store a floating point  
    myInteger = 12;    // 12 = constant integer  
    myFloat = 12.0f;   // 12.0f = constant floating point  
    mySymbol = '@';    // '@' = constant character  
    myBoolean = true;  // true = constant boolean  
    return 0;  
}
```



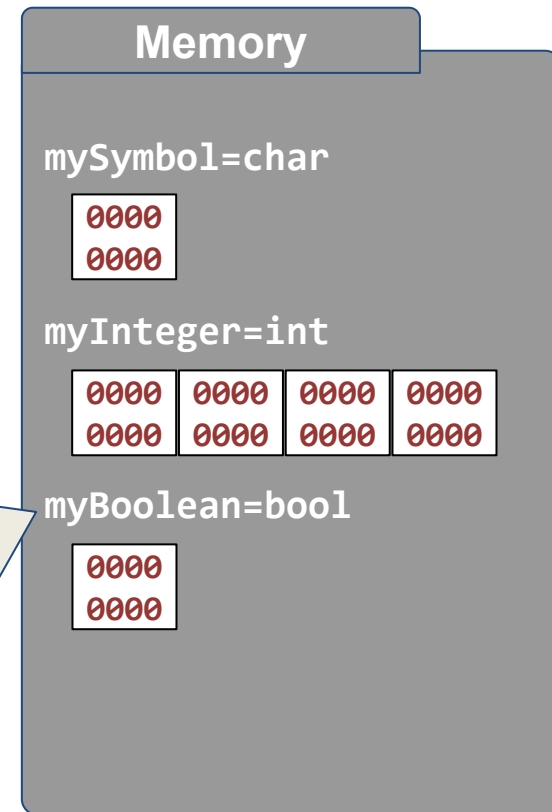
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    mySymbol = '@';    // '@' = constant character  
    myBoolean = true;  // true = constant boolean  
    return 0;  
}
```



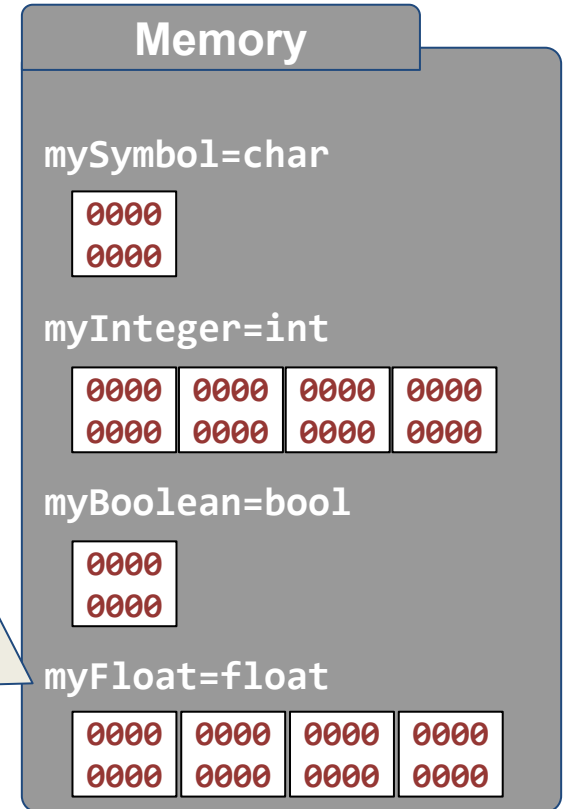
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    myFloat = 12.0f;   // 12.0f = constant floating point  
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    myBoolean = true;  // true = constant boolean  
    return 0;  
}
```



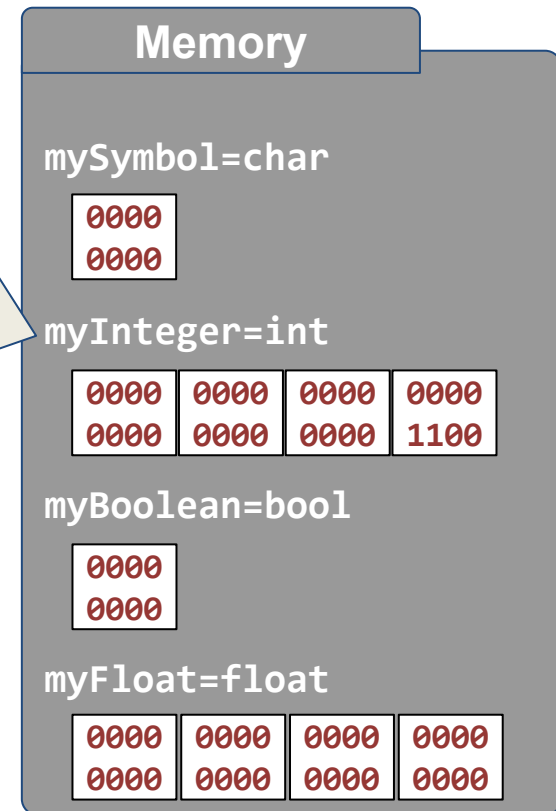
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    myInteger = 12;    // 12 = constant integer  
    myFloat = 12.0f;   // 12.0f = constant floating point  
    mySymbol = '@';    // '@' = constant character  
    myBoolean = true;  // true = constant boolean  
    return 0;  
}
```



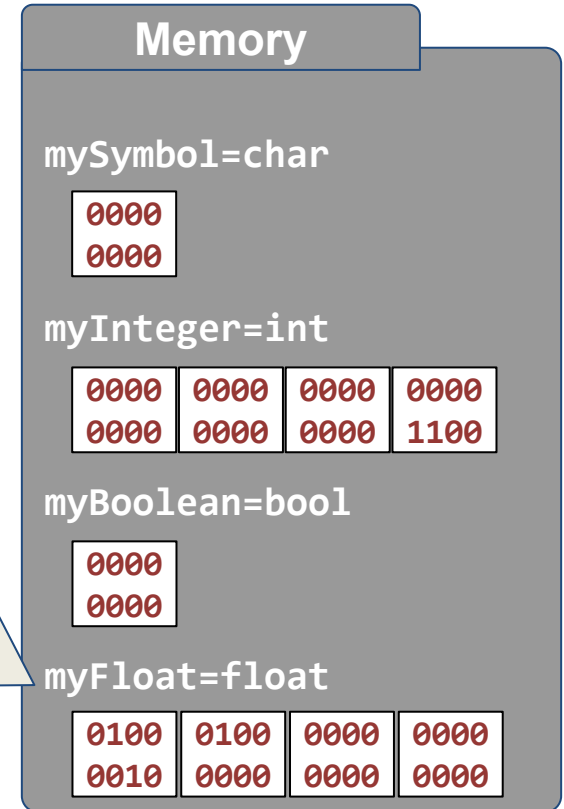
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    myInteger = 12;    // 12 = constant integer  
    myFloat = 12.0f;   // 12.0f = constant floating point  
    mySymbol = '@';    // '@' = constant character  
    myBoolean = true;  // true = constant boolean  
    return 0;  
}
```



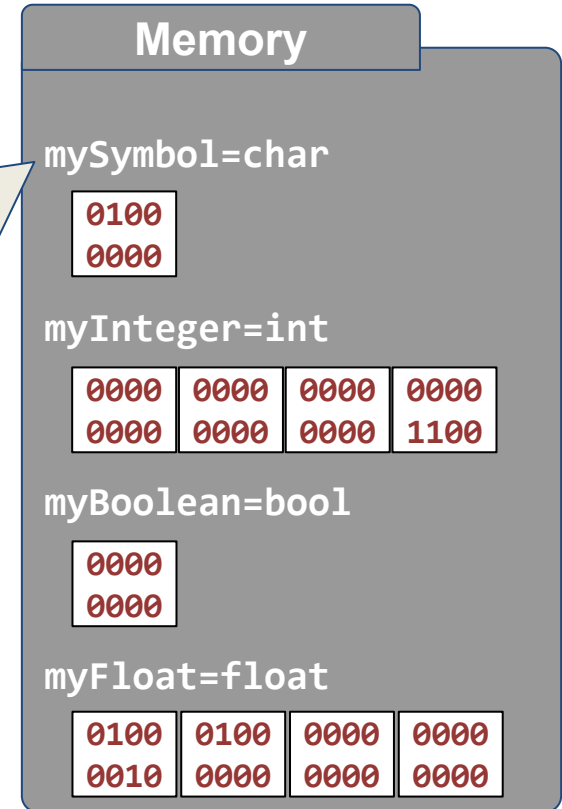
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```



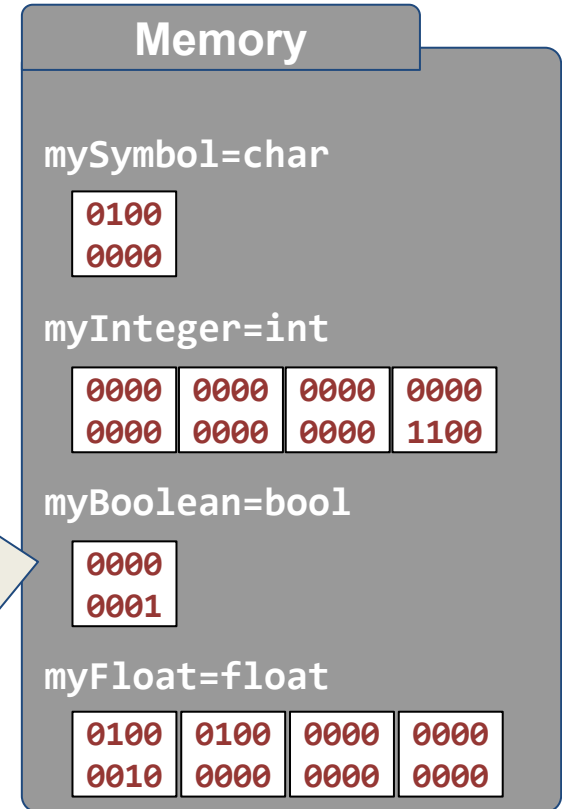
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    myInteger = 12;    // 12 = constant integer  
    myFloat = 12.0f;   // 12.0f = constant floating point  
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    return 0;  
}
```



2.3. Data types: A (simplified) Memory View

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/* reserving variables */  
int main() {  
    char mySymbol;    // store one character  
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    myInteger = 12;    // 12 = constant integer  
    myFloat = 12.0f;    // 12.0f = constant floating point  
    mySymbol = '@';    // '@' = constant character  
    myBoolean = true;    // true = constant boolean  
    return 0;  
}
```



2.3. Data types and variables

- There are few basic types in C++:
 - **int** stored in 4 bytes, range from -2147483648 to 2147483647
 - **float** stored in 4 bytes ([IEEE754](#)), range from -3.4×10^{38} to 3.4×10^{38}
 - **double** stored in 8 bytes ([IEEE754](#)), range from -1.7×10^{308} to 1.7×10^{308}
 - **char** stored in 1 byte (see [ASCII](#) table)
 - **bool** stored in 1 byte
- **Constants** for these type are visible from how they are written:
 - **int** whole numbers, e.g.: 729, -3628, 0, -12632832
 - **float** numbers with decimal range and f, e.g.: 3.612f, 5.2f, 0.001f
 - **double** numbers with decimal range, e.g.: 3.612, 5.2, 0.001
 - **char** a character between single quotes, e.g.: '?'
 - **bool** either true or false

2.3. Data types and variables

Type	SUFFIX	Example	Notes
<code>int</code>	/	2	
<code>unsigned int</code>	<code>u</code> , <code>U</code>	<code>3u</code>	
<code>long int</code>	<code>l</code> , <code>L</code>	<code>8L</code>	
<code>long unsigned</code>	<code>ul</code> , <code>UL</code>	<code>2ul</code>	
<code>long long int</code>	<code>ll</code> , <code>LL</code>	<code>4ll</code>	
<code>long long unsigned int</code>	<code>ull</code> , <code>ULL</code>	<code>7ULL</code>	
<code>float</code>	<code>f</code> , <code>F</code>	<code>3.0f</code>	only decimal numbers
<code>double</code>		<code>3.0</code>	only decimal numbers

C++23 Type	SUFFIX	Example	Notes
<code>std::bfloat16_t</code>	<code>bf16</code> , <code>BF16</code>	<code>3.0bf16</code>	only decimal numbers
<code>std::float16_t</code>	<code>f16</code> , <code>F16</code>	<code>3.0f16</code>	only decimal numbers
<code>std::float32_t</code>	<code>f32</code> , <code>F32</code>	<code>3.0f32</code>	only decimal numbers
<code>std::float64_t</code>	<code>f64</code> , <code>F64</code>	<code>3.0f64</code>	only decimal numbers
<code>std::float128_t</code>	<code>f128</code> , <code>F128</code>	<code>3.0f128</code>	only decimal numbers

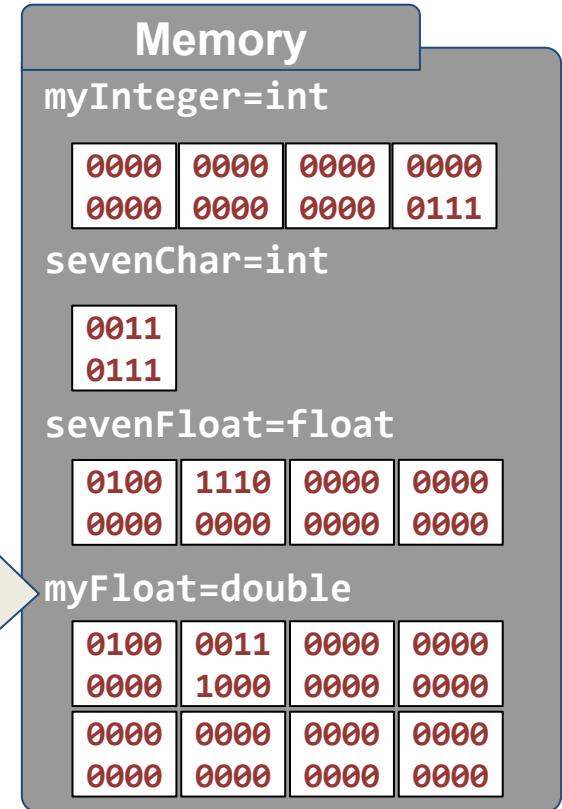
2.3. Data types and variables

Representation	PREFIX	Example
Binary C++14	0b	0b010101
Octal	0	0307
Hexadecimal	0x or 0X	0xFFA010

C++14 also allows *digit separators* for improving the readability `1'000'000`

2.3. Data types: Impact in memory

```
/* reserving variables */  
int main() {  
    int sevenInteger = 7;        // seven as integer  
    char sevenChar = '7';        // seven as character  
    float sevenFloat = 7.0f;     // seven as float  
    double sevenDouble = 7.0;   // seven as double  
    return 0;  
}
```



2.3. Data types and variables

When you need a variable, you need to **declare** it first (and you can give them a value straight away, this is called **initialization**):

```
char mySymbol = '&';    // store one character and set it to '&'
int myNumber;          // store an integer, no initial value
bool areWeDone = false; // stores a boolean, set to false
float heightInMeters = 1.85f; // stores 1.85 as a float
double highPrecision;   // stores a double floating point number
```

Later, you can give variables **new values**:

```
areWeDone = true;    // we have now set this variable to true
highPrecision = 0.0; // we have now set this variable to 0.0
```

Multiple variables can be declared at once: `int myNum = 3, yourNum = 8;`

2.3. Data types and variables

Example: Initialize a character to **a**, show its value in the terminal, then change the value to a **q**, then show it in the terminal again.

```
#include <iostream> // to allow use of std::cout and std::endl
int main() {
    char mySymbol; // variable to hold a character
    mySymbol = 'a';
    std::cout << mySymbol << std::endl; // prints out "a" and newline
    mySymbol = 'q';
    std::cout << mySymbol << std::endl; // prints out "q" and newline
    return 0;
}
```

2.3. Data types and variables: auto

C++11 The **auto** keyword specifies that the type of the variable will be automatically deduced by the compiler (from its initializer)

```
auto a = 1 + 2;    // 1 is int, 2 is int, 1 + 2 is int!  
//      -> 'a' is "int"  
auto b = 1 + 2.0; // 1 is int, 2.0 is double. 1 + 2.0 is double  
//      -> 'b' is "double"
```

auto can be very useful for maintainability and for hiding complex type definitions

```
for (auto i = k; i < size; i++)  
    ...
```

On the other hand, it may make the code less readable if excessively used because of type hiding

Example: `auto x = 0;` in general makes no sense (`x` is `int`)

2.4. Variables and scope

- A variable only exists within a **scope** (block of code, usually between curly braces { and }) and is deleted after the scope ends (after a })
- Variable names cannot use names that are already taken

```
{ // from here starts one scope:
  int a = 3, b = 1;
  { // from here starts another scope:
    c = a + b; // error: c doesn't exist here yet
    int c = 0;
    c += a; // this works, c is defined here
  }
  b = c; // error: c doesn't exist here
  double a = 2.1; // error: a already taken
}
```

2.5. Type conversions

- Variables can sometimes take values from other variables and constants that do not have the same type, **implicitly** converting them
- We'll stick to **explicit conversion**, using the type in braces:

```
double myDouble = 1.1;
int aNumber = 5;
char c = 'a';
bool b = true;
myDouble = (double)aNumber; // this works: myDouble == 5.0
myDouble = (double)c;       // this works: myDouble == 97.0
aNumber = (int)myDouble;    // works:      aNumber == 97
c = (char)98.0f;            // works too: c == 'b'
```

2.5. Type conversions

Example: Find out what the ASCII-codes are for the symbols '?', '&', and '#'

```
#include <iostream> // to allow use of std::cout and std::endl
int main() {
    char question = '?'; // three variables to hold characters
    char ampersand = '&'; // variable to hold a character
    char hash = '#'; // variable to hold a character
    std::cout << (int)question << std::endl; // print ASCII code for '?'
    std::cout << (int)ampersand << std::endl; // print ASCII code for '&'
    std::cout << (int)hash << std::endl; // print ASCII code for '#'
    return 0;
}
```



Homework: Can you write this program in a more memory-efficient way?

3.1. Statements and assignments

3.2. Priority

3.3. Blocks of statements

3.4. **if** and **switch**

3.5. Repetitions / loops:

3.5.1. the **while** loop

3.5.2. the **do while** loop

3.5.3. the **for** loop

3.1. Statements and assignments:

- Variables are the program's data, statements specify what to do with the data
- Statements *always* end with `;` and are executed sequentially
- Assignments *always* calculate the value of what is right of `=` and return this:

```
int x, y, mult;
bool b;
x = 2;           // assignment returns 2
mult = 1;        // assignment returns 1
y = x * 7 / 2;   // y = ?      (try these out yourself
b = ( (x + y) >= 13 ); // b = ?      after learning about
x += -5;         // x = ?      operators and
mult *= x - y;   // mult = ?   priority in the next
b = mult != 1337; // b = ?   slides)
```

3.1. Statements and assignments:

Operators that we will use in this course:

Arithmetic operators:	+	-	*	/	%	++	--
Relational operators:	>	>=	==	!=	<=	<	? :
Logical operators:	&&		!				
Assignment operators:	=	+=	-=	*=	/=	%=	
	<<=	>>=					
Three-way comparison operator:	<=>						

unary operators
binary operators

unary and binary operators
ternary operator

3.1. Statements and assignments:

Arithmetic operators (try out yourself):

```
int x=5, y=9, width, length, multiply, division, remainder;

width      = x + y;           // addition:      14
length     = width - 1;      // subtraction:  13
multiply   = x * y;          // multiplication: 45
division   = x / y;          // division:      0 (why?)
remainder  = x % y;          // modulo (remainder after division): 5
x++;        // increment: x = x + 1:  6
y--;        // decrement: x = x - 1:  8
length = width = y;          // an assignment returns a value: 8
multiply = (x = 2) * (y = 5); // (bad style) : 10
```

3.1. Statements and assignments:

Import to note:

- (Arithmetic) Operators do not exist for each type
for example, % (modulo) does not exist for **float** or **double**
- Operators might have different behavior between types

```
int x = 7, y = 3, z;  
z = x / y;           // note: z will get the value 2, since the  
                     // operator '/' operates on two integers !
```

3.1. Statements and assignments:

Arithmetic operators, a first example (difficulty level: 🌶️)

```
/**  
  Write a program that initializes two integers 'number1' and 'number2',  
  and tests whether number1 is a multiple of number2. Put this result in the  
  boolean variable 'result' below.  
*/  
  
int main() {  
  bool result = false;  
  
  return (int) result;  
}
```

3.1. Statements and assignments:

Relational and logical operators (try out yourself):

```
double f1 = 15.2, f2 = 31.6;
bool b1 = true, b2 = false;
std::cout << (f1 == f1);           // true -> 1
std::cout << (b1 != b1);           // false -> 0
std::cout << (b1 == true);         // true -> 1
std::cout << (f1 < f2);             // true -> 1
std::cout << (f1 <= f1);            // true -> 1
std::cout << ((f1 > f1) && (!b1));  // false -> 0
std::cout << ((b1 != b2) || (f2 >= f1)); // true -> 1
std::cout << (b1 || b2);            // true -> 1
std::cout << ( (f1 > 10.0) ? 'y' : 'n' ); // y
```

3.1. Statements and assignments:

Assignment operators (try out yourself):

```
float x = 5.1f, y = 9.2f;  
int z = 7;
```

```
x = y + 1.0f;           // results in x having the value 10.2f  
y -= x;                // y = y - x  
x += 1.0f;             // x = x + 1.0  
y /= 2.0f;             // y = y / 2.0  
z %= 3;                // z = z % 3 (note z is integer)
```

3.1. Statements and assignments:

Three-way comparison operator or spaceship operator `<=>` (C++20) returns an *object* that can be directly compared with a positive, a 0, or negative integer:

```
(3 <=> 5) == 0;    // false
('a' <=> 'a') == 0; // true
(3 <=> 7) < 0;     // true
(7 <=> 5) < 0;     // false
```


3.1. Statements and assignments:

example 00 (difficulty level: 🌶️🌶️):

```
/**
 * Try to figure out what is happening in the code below. Then try to compile the
 * code, and then change the commented part so that the code's output becomes 1:
 */
#include <iostream> // to allow use of std::cout and std::endl
int main() {
    auto i = 7;      // what type is variable i?
    auto j = 9.0;    // what type is variable j?

    bool ret = ( ( i <=> j ) == 0 ); // change the '== 0' part so that the output is 1

    std::cout << ret << std::endl;
    return 0;
}
```

3.2. Priority

- Operators are not always executed from left to right, as statements
- **Use braces** to avoid having to learn the table below by heart:

Prio. Operators

11	,
10	=, +=, -=, *=, /=, % =, ? :
9	
8	&&
7	<, >, <=, >=
6	<<, >>
5	+, -
4	*, /, %
3	prefix ++, prefix --, unary -, unary +, !, (type), new, delete
2	suffix ++, suffix --, ., -> ,
1	::

Associativity

left to right
right to left
left to right
left to right
left to right
left to right
left to right
left to right
right to left
left to right
left to right

3.2. Priority

- Examples:

```
int a = 2, b = 3, c = 4;  
a = b * c + d;      // a = ((b * c) + d)  
a /= b * c % d;     // a = a / ((b * c) % d)  
a += b = c + d;     // a = a + (b = c + d)
```

Beware of prefix and postfix increment / decrement operators:

```
a = 10;  
b = ++a;  
// a = 11, b = 11
```

```
a = 10;  
b = a++;  
// a = 11, b = 10
```

3.3. Blocks

- Statement sequences and are executed one by one, from left to right:
`length = 10; width = 15; surface = length * width;`
- A block of statements thus implements a function (e.g., between the curly braces `{` and `}` for `main`) and can be used anywhere where a statement can appear. But beware that variables defined there only 'live' in the block:

```
int main() {  
    int length, width, surface;  
    {  
        length = 10; width = 15;  
        surface = length * width;  
    }  
    return 0;  
}
```

```
int main() {  
    int length = 10, width = 15;  
    {  
        int surf = length * width;  
    }  
    return surf; // error: surf unknown  
}
```

3.4. Selection statements: **if** and **switch**

- Depending on a condition, selection statements can either execute the next statement, or not

- Simply for one case:

```
if ( number < 0 )    // if number is negative
    sign = '-';      // then the sign is '-'
```

- For both cases:

```
if ( number < 0 )    // if number is negative
    sign = '-';      // then the sign is '-'
else                 // otherwise:
    sign = '+';      // the sign is '+'
```

3.4. Selection statements: if and switch

Conditions often use relational operators:

```
int x, y, sum, counter, minimum;

if (x > y) ...           // is x bigger than y?
if (x >= y) ...          // is x bigger or equal than y?
if (sum == x + y) ...    // is sum equal to (x+y) ?
if (x != y) ...          // is x different from y?
if (counter < 100) ...    // is counter smaller than 100?
if (x + 1 <= 1 - y) ...   // is (x+1) smaller or equal to (1-y)?

minimum = (x < y)? x : y; // minimum gets a new value of ...
                        // if ( x < y ), then x, else y
```

3.4. Selection statements: if and switch

Conditions also often use logical operators:

```
int x, y, counter;
bool readFlag, writeFlag;

if (readFlag || writeFlag) ...    // logical OR: readFlag or
                                   // writeFlag need to be true,
                                   // will be skipped if both are false

if ((x != 0) && (y / x < 5)) ...   // logical AND: both y/x needs to be
                                   // smaller than 5 and x shouldn't be 0

if (!(x < 0)) ...                 // NOT: the same as if (x >= 0)
```

3.4. Selection statements: if and switch

Nesting if statements:

```
if (number == 0)
    sign = 0;
else
    if (number > 0)
        sign = +1;
    else
        sign = -1;
```

Alternatively, using the (? :) operator:

```
sign = (number == 0) ? 0 : ( (number > 0) ? +1 : -1 );
```


3.4. Selection statements: if and switch

Nesting if statements can be tricky, **use curly braces**

```
if ( x == y )  
    if ( y == z )  
        allEqual = true;  
else  
    allEqual = false;
```



```
if ( x == y ) {  
    if ( y == z )  
        allEqual = true;  
}  
else  
    allEqual = false;
```



```
if ( x == y )  
    if ( y == z )  
        allEqual = true;  
else  
    allEqual = false;
```



```
if ( x == y ) {  
    if ( y == z )  
        allEqual = true;  
    else  
        allEqual = false;  
}
```

3.4. Selection statements: **if** and **switch**Nesting many **if** statements:

```
if (menuItem == 1) {  
    ...  
} else if (menuItem == 2) {  
    ...  
} else if ((menuItem == 3) ||  
           (menuItem == 4)) {  
    ...  
} else if (menuItem == 5) {  
    ...  
} else {  
    ...  
}
```

Using one **switch** statement:

```
switch (menuItem) {  
    case 1: ...  
        break;  
    case 2: ...  
        break;  
    case 3:  
    case 4: ...  
        break;  
    case 5: ...  
        break;  
    default: ...  
        break;  
}
```

3.5. Loops

3.5.1. The `while` loop:

```
int i, sum;
sum = 0;
i = 1;
while ( i < 7 ) { // this block
    sum += i;     // is executed
    i++;          // repeatedly
}
```

result:

sum: 0, 1, 3, 5, 9, 14, 20

3.5.2. The `do while` loop:

```
int i, sum;
sum = 0;
i = 1;
do { // this block
    sum += i; // is executed
    i++;      // repeatedly
} while ( i < 7 );
```

result:

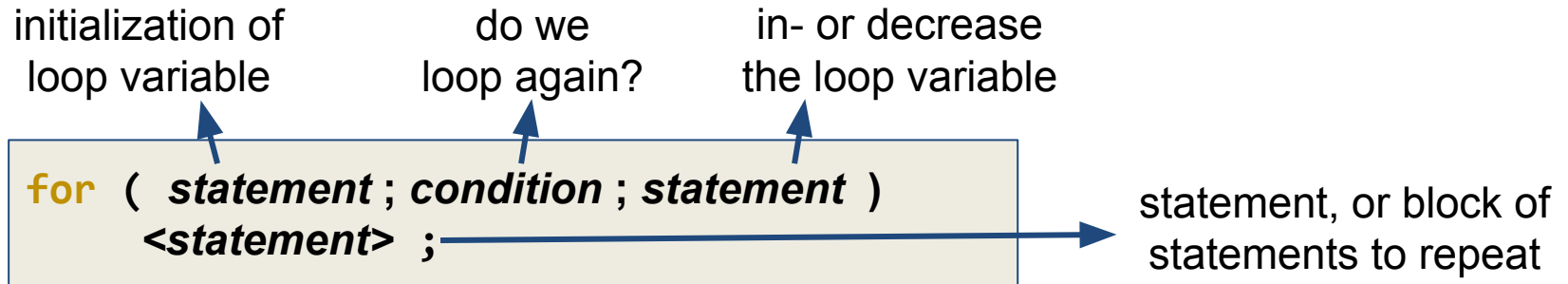
sum: 0, 1, 3, 5, 9, 14, 20

3.5. Loops

3.5.3. The for loop:

```
int i, sum = 0;
for ( i = 0; i <= 10; i++ ) { // this block
    sum += i;                // is executed repeatedly
}
```

Template:



3.5. Loops: `break` and `continue`

- **`break`** terminates a loop. The rest of the loop body will not be executed:

```
int num = 10;
while (num > 0) {
    if (num == 5) break; // stop after num has reached 5
    num--;
}
```

- **`continue`** does not terminate the loop, but just skip the rest of the loop body:

```
int num = 10;
while (num > 0) {
    if (num == 5) continue; // when num == 5, don't decrement
    num--;
}
```

3.5. Loops: When do we use which loop type?

- **for** loop:
 - for a given range (e.g. "for all $i = 1 \dots N$ ")
 - when you automatically need a loop variable
- **while** loop:
 - when the (maximal) number of repetitions is not known beforehand
 - when the repetition conditions are more complex
- **do while** loop:
 - when a block needs to be repeated at least once

3.5. Loops: example 02 (difficulty level: 🌶️)

```
/**  
    Write a program that prints out a series of numbers, starting at 120.0 and where  
    each next number is seven less than the previous one. Stop once the number is  
    smaller than 43.7  
*/  
#include <iostream> // to allow use of std::cout and std::endl  
int main( ) {  
  
    return 0;  
}
```

3.5. Loops: example 03 (difficulty level: 🌶️🌶️)

```
/**  
Write a program that asks the user for a number, and then prints out this number  
in the terminal, followed by the half of the previous number until  
the result is smaller than ten. So for 100 it would give out: 100, 50, 25.5, 12.25  
*/  
#include <iostream> // to allow use of std::cout and std::endl  
int main( ) {  
  
    return 0;  
}
```


3.5. Loops: example 04 (difficulty level: 🌶️🌶️)

```
/**  
    Write a program that counts from 131 down till 23, one number per line in the  
    the terminal, and prints out "hop", if the number is a multiple of 7.  
*/  
#include <iostream> // to allow use of std::cout and std::endl  
int main( ) {  
  
    return 0;  
}
```

3.5. Loops: example 05 (difficulty level: 🌶️🌶️🌶️)

```
/**  
Write a program that prints in the terminal all prime numbers from 3 till 99.  
Remember: A number is a prime when any division by a smaller number results in  
a remainder that is never zero.  
*/  
  
#include <iostream> // to allow use of std::cout and std::endl  
int main( ) {  
  
    return 0;  
}
```

3.5. Loops: example 06 (difficulty level: 🌶️🌶️🌶️)

/**

Write a program that draws in the terminal a big X out of the character 'X', depending on the variable int size (with size = 3, 4, ..., 20):

size = 3: size = 4: size = 5: etc.

X X

X X

X X

X

XX

X X

X X

XX

X

X X

X X

X X

*/

#include <iostream> // to allow use of std::cout and std::endl

int main() {

return 0;

}

3.5. Loops: example 07 (difficulty level: 🌶️🌶️🌶️🌶️)

```
/**  
Write a program that draws in the terminal a bigger X out of the character 'X',  
depending on the variable int size (with size = 3, 4, ..., 20):  
size = 3:      size = 4:      size = 5:      etc.  
  XX X        XX  X          XX   X  
   XX         XXX           XX  X  
  X XX        XXX           XX  
                X  XX       X  XX  
                  X   XX      */  
#include <iostream> // to allow use of std::cout and std::endl  
int main( ) {  
  
    return 0;  
}
```

4.1. Functions and their parameters

4.2. Recursive Functions

4.3. Call by Value

4.4. `inline` Functions, Overloading, `=delete`

4.5. Default Parameters and Function Attributes

4.6. Header files and Modules

4.7. Miscellaneous: Variadic arguments and Coroutines