C/C++ Programming

Programming languages I

One can, e.g., distinguish:

scripting languages

- bash, csh → Unix shell
- Perl, Python
- IRAF, IDL, Midas → especially for data reduction in astrophysics

compiler-level languages

- C/C++ → very common, therefore our favorite language
- Fortran → very common in astrophysics, especially in radiative transfer

Programming languages II

	scripting language	compiler-level language
examples	shell (bash, tcsh), Perl, Mathematica, MATLAB, ...	C/C++, Fortran, Pascal, ...
source code	directly executable	translated to machine code, e.g., 0x90 → no operation (NOP)
runtime behavior	interpreter runs as a program → full control over execution → error messages, argument testing	error handling difficult → task of the programmer, often only crash
speed	usually slow → analysis tools	very fast by optimization → simulations, number crunching

→ moreover, also bytecode compiler (JAVA) for virtual machine,
Just-in-time (JIT) compiler (JavaScript, Perl)

- C is a *procedural* (imperative) language
- C++ is an *object oriented* extension of C with the same syntax
- C++ is because of its additional structures (template, class) $\gg$ C

Basic structure of a C++ program

```
#include <iostream>
using namespace std ;
int main () {
    instructions of the program ;
    // comment
    return 0 ;
}
```

every instruction must be finished with a `;` (semicolon) !

Compiling a C++ program:

source file
`.cpp, .C`

⇓

compiler + linker
`.o, .so, .a`

⇓

executable program
`a.out, program`

Command for compiling + linking:

```
g++ -o program program.cpp
```

(GNU compiler for C++)

- only compiling, do not link:

  `g++ -c` *program*`.cpp`

  creates *program*`.o` (object file, not executable)

- option `-o` *name* defines a name for a file that contains the executable program, otherwise program file is called: `a.out`

  the name of the executable program can be arbitrarily chosen

Simple program for output on screen I

Example: C++ output via streams

```
#include <iostream>

using namespace ::std ;

int main () {

    cout << endl << "Hello world!" << endl ;

    return 0 ; // all correct

}
```

Simple program for output on screen II

- `<iostream>` … is a C++ library (input/output)
- `main()` … program (function)
- `return 0` … returns the return value 0 to main (all ok)
- source code can be freely formated, i.e., it can contain an arbitrary number of spaces and empty lines (white space) → useful for visual structuring
- comments are started with `//` - everything after it (in the same line) is ignored, C has only `/* comment */` for comment blocks
- `cout` … output on screen/terminal (C++)
- `<<` … output/concatenate operator (C++)
- string `"Hello world!"` must be set in quotation marks
- `endl` … manipulator: new line and stream flush (C++)
- a block several instructions which are hold together by curly braces

Functions I

C/C++ is a procedural language
The procedures of C/C++ are *functions*.

- Main program: function with specific name `main(){}`
- every function has a type (for return), e.g.: `int main (){}`
- functions can get arguments by call, e.g.:
  `int main (int argc, char *argv[]){}`
- functions must be *declared before* they can be called in the main program,
  e.g., `void swap(int &a, int &b) ;`
  or included via a header file:
  `#include <cmath>`
- within the curly braces `{ }`, the so-called function body, is the *definition* of the function (what shall be done how), e.g.:
  `int main () { return 0 ; }`

Functions II

Example

```
#include <iostream>
using namespace std ;

float cube(float x) ;

int main() {
  float x = 4. ;
  cout  << cube(x) << endl ;
  return 0 ;
}

float cube(float x) {
  return x*x*x ;
}
```

Variables

- A variable is a piece of memory.
- in C/C++ data types are explicit and static

We distinguish regarding visibility ("scope"):

- global variables → declared outside of any function, before `main`
- local variables → declared in a function or in a block `{ }` , only there visible

... regarding data types → intrinsic data types:

- `int` → integer, e.g., `int n = 3 ;`
- `float` → floats (floating point numbers),
  e.g., `float x = 3.14, y = 1.2E-4 ;`
- `char` → characters, e.g., `char a_character ;`
- `bool` → logical (boolean) variables, e.g., `bool btest = true ;`

Integer data types I

Integer numbers are represented *exactly* in the memory with help of the binary number system (base 2), e.g.

$$13 = 1 \cdot 2^3 + 1 \cdot 2^2 + 0 \cdot 2^1 + 1 \cdot 2^0 \mathrel{\widehat{=}} \boxed{1}\boxed{1}\boxed{0}\boxed{1}^{\,1} \quad \text{(binary)}$$

In the assignment

```
a = 3
```

3 is an integer literal (literal constant). Its bit pattern ($3 = 1 \cdot 2^0 + 1 \cdot 2^1 \mathrel{\widehat{=}} \boxed{1}\boxed{1}$) is inserted at the corresponding positions by the *compiler*.

[1]doesn't correspond necessarily to the sequential order used by the computer → "Little Endian": store least significant bit first, so actually: 1011

Integer data types II

on 64-bit systems

`int`	compiler reserves 32 bit (= 4 byte) of memory 1 bit for sign and $2^{31} = 2\,147\,483\,648$ values (incl. 0): $\rightarrow$ range: `int` $= -2\,147\,483\,648 \ldots +2\,147\,483\,647$
`unsigned int`	32 bit, no bit for sign $\rightarrow 2^{32}$ values (incl. 0) `unsigned int` $= 0 \ldots 4\,294\,967\,295$
`long`	on 64 bit systems: 64 bit (= 8 byte), 1 bit for sign: $-9.2 \times 10^{18} \ldots 9.2 \times 10^{18}$ (quintillions)
`unsigned long`	64 bit without sign: $0 \ldots 1.8 \times 10^{19}$

and also: `char` (1 byte), smallest addressable (!); `short` (2 byte) ; `long long` (8 bytes)

Two's complement

Table: Representation: unsigned value (0s), value and sign (sig), two's complement (2'S) for a nibble ($\frac{1}{2}$ byte)

binary	0s	sig	2'S
0000	0	0	0
0001	1	1	1
	...		
0111	7	7	7
1000	8	-0	-8
1001	9	-1	-7
	...		
1111	15	-7	-1

Disadvantages of representration as value and sign:
$\exists$ 0 *and* -0; Which bit is sign? ($\rightarrow$ const number of digits, fill up with 0s);

Advantage of 2'S:
negative numbers always with highest bit=1

$\rightarrow$ cf. $+1 + -1$ bitwise for value & sign vs. 2'S

Floating point numbers are an approximate representation of real numbers.
Floating point numbers can be declared via, e.g.,:

```
  float radius, pi, euler, x, y ;
  double  radius, z ;
```

Valid assignments are, e.g.,:

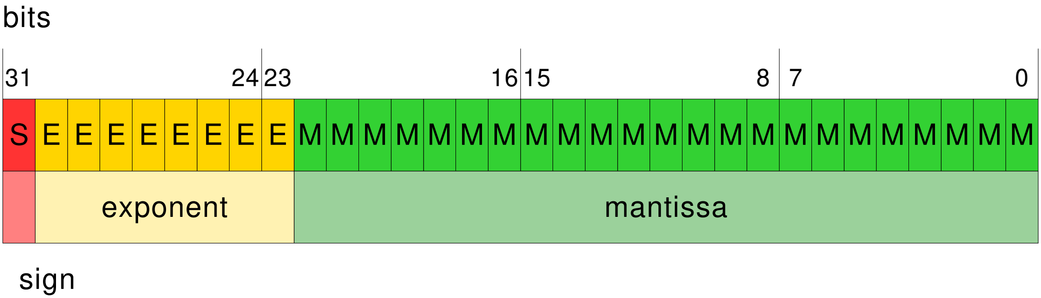
```
x = 3.0 ;
y = 1.1E-3 ;
z = x / y ;
```

- representation (normalization) of floating point numbers are described by standard IEEE 754 :

$$x = s \cdot m \cdot b^{e} \tag{1}$$

with base $b = 2$ (IBM Power6: also $b = 10$), sign s, and normalized significand (mantissa) m, bias

- So for 32 Bit (Little Endian†), 8 bit exponent, 23 bit mantissa:



(† read each part: $\rightarrow$)

Floating point data types III

- mantissa is *normalized* to the form (e.g.)

  $$1{,}0100100 \times 2^4$$

  i.e. with a 1 before the decimal point. This 1 is not stored, so $m = 1.f$

  Moreover, a bias (127 for 32 bit, 1023 for 64 bit) is added to the exponent (results in non-negative integer)

Example: Conversion of a decimal number to IEEE-32-Bit

172.625	base 10
10101100.101×2^0	base 2
1.0101100101×2^7	base 2 normalized

add bias of 127 to exponent $= 134 = 1 \cdot 2^7 + \ldots + 1 \cdot 2^2 + 1 \cdot 2^1 + 0 \cdot 2^0$

0 10000110 01011001010000000000000

Floating point data types IV

- single precision (32 bit) `float`: exponent 8 bit, significand 23 bit

$$-126 \leq e \leq 127 \text{ (basis 2)}$$

$$\rightarrow \approx 10^{-45} \ldots 10^{38}$$

$$\text{digits: 7-8 } (= \log 2^{23+1} = 24 \log 2)$$

- for 64 bit (double precision) – `double`: exponent 11 bit, significand 52 bit

$$-1022 \leq e \leq 1023 \text{ (basis 2)}$$

$$\rightarrow \approx 10^{-324} \ldots 10^{308}$$

$$\text{digits: 15-16 } (= \log 2^{52+1})$$

Floating point data types V

some real numbers cannot be presented exactly in the binary numeral system (cf. 1/3 in decimal):

$$0.1 \approx 1.10011001100110011001101 \times 2^{-4} \tag{2}$$

Warning

Do not compare two floating point numbers blindly for equality (e.g., `0.362 * 100.0 == 36.2`), but rather use an accuracy limit:
`abs( x - y ) <= eps`, better: relative error
`abs(1-y/x) <= eps`

Floating point data types VI

Floating point arithmetics

Subtraction of floating point numbers

consider $1.000 \times 2^5 - 1.001 \times 2^1$ (only 3 bit mantissa)
$\rightarrow$ *bitwise subtraction*, requires same exponent

$$
\begin{array}{rll}
 & 1.000\,0000 & \times 2^5 \\
- & 0.000\,1001 & \times 2^5 \\
\hline
 & 0.111\,0111 & \times 2^5 \text{ infinite precision} \\
 & 1.110\,111 & \times 2^4 \text{ shifted left to normalize} \\
 & 1.111 & \times 2^4 \text{ rounded up, as last digits} > 1/2 \text{ ULP}^\dagger
\end{array}
$$

†unit in the last place = spacing between subsequent floating point numbers

Floating point data types VII

Properties of floating point arithmetics (limited precision):

- loss of significance / catastrophic cancellation: occurs for subtraction of almost equal numbers

Example for loss of significance

$\pi - 3.141 = 3.14159265\ldots - 3.141$ with 4-digit mantissa; maybe expected: $= 0.00059265\ldots \approx 5.927 \times 10^{-4}$; in fact: 1.0000×10^{-3}, because π is already rounded to 3.142

- absorption (numbers of different order of magnitude): addition of subtraction of a very small number does not change the larger number

Example for absorption

for 4-digit mantissa: $0.001 + 100 = 100$: $1.000 \times 10^2 + 1.000 \times 10^{-3} =$ $1.000 \times 10^2 + 0.000\,01 \times 10^2 = 1.000 \times 10^2 + 0.000 \times 10^2 = 1.000 \times 10^2$, same for subtraction

- distributive and associative law usually not fulfilled, i.e. in general

$$(x+y)+z \neq x+(y+z) \tag{3}$$
$$(x\cdot y)\cdot z \neq x\cdot(y\cdot z) \tag{4}$$
$$x\cdot(y+z) \neq (x\cdot y)+(x\cdot z) \tag{5}$$
$$(x+y)\cdot z \neq (x\cdot z)+(y\cdot z) \tag{6}$$

- solution of equations, e.g., $(1+x)=1$ for 4-bit mantissa solved by any $x<10^{-4}$ (see absorption) $\rightarrow$ *smallest* float number ϵ with $1+\epsilon>1$ called machine precision

Multiplication and division of floating point numbers:
mantissas multiplied/divided, exponents added/subtracted
$\rightarrow$ no cancellation or absorption problem

Floating point data types IX

Guard bit, round bit, sticky bit (GRS)

- in floating point arithmetics: if mantissa shifted right $\rightarrow$ loss of digits
- therefore: during calculation 3 extra bits (GRS)
  Guard bit: 1st bit, just extended precision
  Round bit: 2nd (Guard) bit, just extended precision (same as G)
  Sticky bit: 3rd bit, set to 1, if any bit beyond the Guard bits non-zero, stays then 1(!)
  $\rightarrow$ sticky
- example

```
                                                  G R S
Before 1st shift: 1.11000000000000000000100 0 0 0
After 1 shift:    0.11100000000000000000010 0 0 0
After 2 shifts:   0.01110000000000000000001 0 0 0
After 3 shifts:   0.00111000000000000000000 1 0 0
After 4 shifts:   0.00011100000000000000000 0 1 0
After 5 shifts:   0.00001110000000000000000 0 0 1
After 6 shifts:   0.00000111000000000000000 0 0 1
After 7 shifts:   0.00000011100000000000000 0 0 1
After 8 shifts:   0.00000001110000000000000 0 0 1
```

GRS bits – possible values and stored values

extended sum	stored value	why
1.0100 000	1.0100	truncated because of GR bits
1.0100 001	1.0100	truncated because of GR bits
1.0100 010	1.0100	rounded down because of GR bits
1.0100 011	1.0100	rounded down because of GR bits
1.0100 100	1.0100	rounded down because of S bit
1.0100 101	1.0101	rounded up because of S bit
1.0100 110	1.0101	rounded up because of GR bits
1.0100 111	1.0101	rounded up because of GR bits

Floating point data types XI

IEEE representation of 32 bit floats:

Number name	sign, exp., f	value
normal	$0 < e < 255$	$(-1)^s \times 2^{e-127} \times 1.f$
subnormal	$e = 0, f \neq 0$	$(-1)^s \times 2^{-126} \times 0.f$
signed zero (± 0)	$e = 0, f = 0$	$(-1)^s \times 0.0$
$+\infty$	$s = 0, e = 255, f = 0$	`+INF`
$-\infty$	$s = 1, e = 255, f = 0$	`-INF`
Not a number	$e = 255, f \neq 0$	`NaN`

- if float $> 2^{128}$ $\rightarrow$ overflow, result may be `NaN` or unpredictable
- if float $< 2^{-128}$ $\rightarrow$ underflow, result is set to 0

If not default by compiler: enable floating-point exception handling (e.g., `-fpe-all0` for `ifort`)

Automatic type conversion

In C/C++ many data type conversions are already predefined, which will be invoked automatically:

```
int main () {
    int a = 3 ;
    double b ;
    b = a ;       // implicit conversion of a to double
    b = 1. / 3 ; // implicit conversion of 3 to double
    return 0.2 ; // implicit conversion of 0.2 to integer 0
}
```

Explicit type conversions (casts) I

Moreover, a type conversion/casting can be done explicitly:

C cast

```
int main () {
  int a = 3 ;
  double b  ;
  b = (double) a ; // type cast
  return 0 ;
}
```

- obviously possible: integer $\leftrightarrow$ floating point
- but also : pointer (see below) $\leftrightarrow$ data types
- Caution: For such C casts there is no type checking during runtime!

Explicit type conversions (casts) II

The better way: use the functions of the same name for type conversion

```
int i, k = 3 ;
float x = 1.5, y ;
i = int(x) + k ;
y = float(i) + x ;
```

Logical variables

```
bool b ;
```

intrinsic data type, has effectively only two different values:

```
bool btest, bdo ;
btest = true ; // = 1
bdot = false ; // = 0
```

but also:

```
btest = 0. ; // = false
btest = -1.3E-5 ; // = true
```

Output via `cout` yields `0` or `1` respectively. By using `cout << boolalpha << b ;` is also possible to obtain `t` and `f` for output.

Note: minimum addressable piece of memory is 1 byte → `bool` needs more memory than necessary

Execution control - `for`-loops I

Executable control constructs modify the program execution by selecting a block for repetition (loops, e.g., `for`) or branching to another statement (conditional, e.g., `if`/ unconditional, e.g., `goto`).

Repeated execution of an instruction/block:

`for` loop

```
for (int k = 0 ; k < 6 ; ++k ) sum = sum + 7 ;

for (float x = 0.7 ; x < 17.2 ; x = x + 0.3) {
    y = a * x + b ;
    cout << x << " " << y << endl;
}
```

Structure of the loop control (header) of the `for` loop:

There are (up to) three arguments, separated by semicolons:

1. initialization of the loop variable (loop counter), if necessary with declaration, e.g.:
   `int k = 0 ;` †
   → is executed *before the first* iteration
2. condition for termination of the loop, usually via arithmetic comparison of the loop variable, e.g.,
   `k < 10 ;`
   is tested *before each* iteration
3. expression: incrementing/decrementing of the loop variable, e.g.,
   `++k` or `--k` or `k += 3`
   is executed *after each* iteration

† interestingly also: `int k = 0, j = 1;`

Increment operators

```
sum += a
```

→ `sum = sum + a`

```
++x
```

→ `x = x + 1` (increment operator)

```
--x
```

→ `x = x - 1` (decrement operator)

Note that there is also a *post* increment/decrement operator: `x++`, `x--`, i.e. incrementing/decrementing is done *after* any assignemnt, e.g., `y = x++`.

Logical operators I - Comparisons/inequalities

→ return either(!) `true` or `false`:

`a > b`	greater than
`a >= b`	greater than or equal
`a == b`	equal
`a != b`	not equal
`a <= b`	less than or equal
`a < b`	less than

Caution!

The exact equality == should not be used for float-type variables because of the limited precision in the representation.

Loops I

Moreover, there exist also:

`while` loops

```
while (x < 0.) x = x + 2. ;

do x = x + 2. ;  // do loop is executed
while (x < 0.) ; // at least once!
```

Instructions for loop control

```
break ;    // stop loop execution / exit current loop
continue ; // jump to next iteration
```

Loops II

In C/C++: no real "for loops"

→ loop variable (counter, limits) can be changed in loop body
slow, harder to optimize for compiler/processor

Recommendation: *local* loop variables

→ declaration in loop header
→ scope limited to loop body

Execution control – conditional statements I

Conditional execution via `if`:

```
if (z != 1.0) k = k + 1 ;
```

Conditional/branching

```
    if (a == 0) cout << "result" ; // one-liner

    if (a == 0) a = x2 ; // branching
    else if (a > 1) {
          a = x1 ;
    }
    else a = x3 ;
```

If the variable used for branching has only discrete values (e.g., `int`, `char`, but not floats!), it is possible to formulate conditional statements via `switch/case`:

Branching II

```
switch (Ausdruck) {
        case value1 : instruction ; break ;
        case value2 : instruction1 ;
                      instruction2 ; break ;
        default     : instruction ;
}
```

Heads up!

Every case instruction section should be finished with a `break`, otherwise the next case instruction section will be executed automatically.

Example: `switch`

```
int k ;
cout << "Please enter number, 0 or 1: " ;
cin >> k ;
switch (k) {
  case    0 : cout << "pessimist" << endl ; break ;
  case    1 : cout << "optimist"  << endl ; break ;
  default   : cout << "neutral" << endl ;
}
```

Declaration and visibility of variables I

Declarations of variables should be at the beginning of a **block**, exception: loop variables

```
float x, y ; // declaration of x and y
int n = 3 ; // declaration and initialization of n
```

Local variables / variables in general

- are only visible within the block (e.g., in `int main() { }`), where they have been declared
- are **local** regarding this block, their value can only be changed within this block
- are unknown outside of this block, i.e., they don't exist there

Global variables

- must be declared outside of any function, e.g., before `main()`
- are visible/known to all following functions within the same program
- have file wide visibility (i.e., if you split your source code into different files, you have to put the declaration into every file)
- are only removed from memory when execution of the program is ended

A locally declared variable will hide a global variable of the same name. The global variable can be still accessed with help of the scope operator `::`, e.g., `cout << ::m ;`

Declaration and visibility of variables III

Global and local variables

```
int m = 0 ;       // global variable

void calc() {
  int k = 0;      // local variable
  m = 1 ;         // ok, global variable
  ++j ;           // error, as j only known in main
}

int main() {
  int j = 3 ;
  ++j ; // ok
  for (int i = 1 ; i < 10 ; ++i)
  {
     j = m + i ; // ok, all visible
  }
  m = j - i ;     // error: i not visible
  return j ;
}
```

Defining constants

Values (e.g., numbers) that do not change during the program execution, should be *defined* as constants:

```
const float e = 2.71828 ;
```

Constants must be initialized during declaration.

After initialization their value cannot be changed.

Use `const` whenever possible!

Character variables

```
char character ;
```

are encoded as integer numbers:

```
char character = 'A' ;
char character = 65 ;
```

mean the same character (ASCII code)

Assignments of character literals to character variables require single quotation marks ' :

```
char yes = 'Y' ;
```

Arrays in C/C++

Static array declaration for a one-dimensional array of type `double`**:**

`double a[5] ;` one-dimensional array with 5 elements of type double (e.g., vectors)

Access to individual elements:

```
total = a[0] + a[1] + a[2] + a[3] + a[4] ;
```

Heads up!

In C/C++ the index for arrays starts always at 0 and runs in this example until 4, so the last element is `a[4]`.

A common source of errors in C/C++ !!!

Note: While the size of the array can be set during runtime, the size cannot be changed after declaration (**static** declaration).

Two-dimensional arrays I

an $m \times n$ matrix (rows $\times$ columns) :

$$
\begin{array}{c} n \text{ columns} \rightarrow \\
\begin{array}{c} m \\ \text{rows} \\ \downarrow \end{array}
\begin{pmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & \dots & & \\ \dots & & & \\ a_{m1} & & & a_{mn} \end{pmatrix}
\end{array}
$$

`int a[m][n]` … static allocation of two-dimensional array, e.g., for matrices (m, n must be constants)

access via, e.g., `a[i][j]`

`i` is the index for the rows,
`j` for the columns.

Two-dimensional arrays II

$$\text{e.g.,}\quad a = \begin{bmatrix} 1 & 2 & 3 \\ 4 & 5 & 6 \end{bmatrix}$$

Note that in C/C++ the second (last) index runs first, i.e. the entries of `a[2][3]` are in this order in the memory :

`a[0][0]`	`a[0][1]`	`a[0][2]`	`a[1][0]`	`a[1][1]`	`a[1][2]`
1	2	3	4	5	6

(row-major order $\rightarrow$ stored row by row)

Initialization of arrays

An array can be initialized by curly braces:

```
int array[5] = {0, 1, 2, 3, 4} ;

short field[] = {0, 1} ; // array field is automatically
                         // dimensioned

float x[77] = {0} ; // set all values to 0
```

Strings

There are no string variables in C. Therefore strings are written to one-dimensional character arrays:

```
char text[6] = "Hello" ;
```

The string literal constant `"Hello"` consists of 5 printable characters and is terminated automatically by the compiler with the null character `\0`, i.e. the array must have a length of 6 characters! Note the double quotation marks!

Example

```
char text[80] ;
cout << endl << "Please enter a string:" ;
cin  >> text ;
cout << "You have entered " << text << " ." << endl ;
```

Pointer variables – or pointer for short – allow a direct access (i.e. not via the name) to a variable.

Declaration of pointers

```
int    *pa  ; // pointer to int
float  *px  ; // pointer to float
int   **ppb ; // pointer to pointer to int
```

A pointer is a variable that contains an address, i.e. it points to a specific part of the memory.
As every variable in C/C++ a pointer variable must have a data type.
The value at address (memory) to which the pointer points, must be of the declared data type.

address	value	variable
1000	0.5	x
1004	42	n
1008	3.141. . .	d
1012	. . . 5926	
1016	H E Y !	salutation
1020	1000	px
1024	1008	pd
1028	1004	pn
1032	1016	psalutation
1036	1028	pp

Pointer III

Pointers must be always initialized before usage!

Initialization of pointers

```
int  *pa ; // pointer to int
int b ;    // int
pa = &b ;  // assigning the address of b to a
```

The character & is called the address operator (“address of”)
(not to be confused with the reference `int &i = b ;`).

Declaration and initialization

```
int b ;
int *pa = &b ;
```

→ content of `pa` = address of `b`

Pointer IV

With help of the dereference operator $*$ it is possible to get access to the value of the variable b, one says, pointer pa is dereferenced:

Dereferencing a pointer

```
int b, *pa = &b ;
*pa = 5 ;
```

Here, $* \ldots$ is the dereference operator and means "value at address of ...".

The part of the memory to which pa points, contains the value 5, that is now also the value of the variable b.

```
cout << b << endl ; // yields 5
cout << pa << endl ; // e.g., 0x7fff5fbff75c
```

Pointer V

Once again:

Pointer declaration:

```
float *pz, a = 2.1 ;
```

Pointer initialization:

```
pz = &a ;
```

Result – output:

```
cout << "address of variable a (content of pz): "
     << pz << endl ;
cout << "content of variable a: "
     << *pz << endl ;
*pz = 5.2 ; // change value of a
```

```
int &n = m ;
m2 = n + m ;
```

- A reference is a new name, an alias for a variable. So, it is possible to address the same part of the memory (variable) by different names within the program. Every modification of the reference is a modification of the variable itself - and vice versa.
- References are declared via the & character (reference operator) and must be initialized instantaneously:

```
int a ;
int &b = a ;
```

- This initialization cannot be changed any more within the program!

Passing variables to functions I

Structure of functions – definition

type name (arg1, ...) { ... }

example: `int main (int argc, char *argv[]) { }`

- in parenthesis: arguments of the function / formal parameters
- when function is called: copy arguments (values of the given variables) to function context
  → *call by value / pass by value*

```
setzero (float x) { x = 0. ; }
int main () {
    float y = 3. ;
    setzero (y) ;
    cout << y ; // prints 3. }
```

Call by value

Pros:

- the value of a passed variable cannot be changed unintentionally within the function

Cons:

- the value of a passed variable can also not be changed on purpose
- for every function call all value must be *copied*
  $\rightarrow$ extra overhead (time)
  (exception: if parameter is an array, only *start address* is passed $\rightarrow$ pointer)

Structure of functions: Call by reference

```
void swap(int &a, int &b) ;
```

Passing arguments as references:

The variables passed to the function swap are changed in the function and keep these values after returning from swap.

```
void swap (int &a, int &b) {
 int t = a ;  a = b ; b = t ; }
```

→ and called via: `swap (n, m) ;`

Thereby we can pass an arbitrary number of values back from a function.

Hint: The keyword `const` prevents that a passed argument can be changed within the function:
`sum (int const &a, int const &b) ;`

Call by pointer

A function for swapping two `int` variables can also be written by using pointers:

```
void swap(int *a, int *b) { // pointers as formal parameters
    int t = *a ; *a = *b ; *b = t ;
}
```

Call in `main()`:

```
  swap (&x, &y) ;  // Passing addresses (!)
                   // of x and y
```

Passing arrays to functions

In contrast to (scalar) variables, arrays are automatically passed by address (pointer) to functions, e.g.,
`myfunc ( float x[] )`

Pointers and references

Pointer variables

- store addresses
- must be dereferenced (to use the value of the spotted variable)
- can be assigned as often as desired to different variables (of the same, correct type) within the program

References

- are alias names for variables,
- can be used by directly using their names (without dereferencing)
- the (necessary!) initialization at declaration cannot be changed later

Besides the intrinsic (/basic) data types there are many other data types, which can be defined by the programmer

struct

```
struct complex {
    float re ;
    float im ;
} ; 
```
[a]

[a] Note the necessary semicolon after the } for structs

In this example the data type `complex` is defined, it contains the *member variables* for real and imaginary part.

Structs and classes – defining new data types II

Structs can be imagined as collections of variables.

struct

```
struct star {
      char full_name[30] ;
      unsigned short binarity ;
      float luminosity_lsun ;
} ;
```

These (self defined) data types can be used in the same way as intrinsic data types:

Declaration of `struct` objects

```
complex z, c ;
star sun ;
```

Concrete structs which are declared in this way are called *instances* or *objects* (→ object-oriented programming) of a class (struct).

Declaration and initialization

```
complex z = {1.1 , 2.2} ;
star sun  = {"Sun", 1, 1.0 } ;
```

The access to *member variables* is done by the *member selection operator* `.` (dot):

Access to members

```
real_part = z.re ;
sun.luminosity_lsun = 1.0 ;
```

It is also possible to define functions (so-called *methods*) within structs:

Member functions

```
struct complex {
      ...
      float absolute () {
            return (sqrt(re*re + im*im)) ;
      }
} ;
complex c = {2., 4.} ;
cout << c.absolute() << endl ;
```

The call of the *member function* is also done with the `.` , the function (method) is associated with the object.

Classes – Example: writing/reading files I

Output to a file by using library `fstream`:

1. `#include <fstream>`
2. create an object of the class `ofstream`:

   `ofstream fileout ;`
3. method open of the class `ofstream`:

   `fileout.open("graphic.ps") ;`
4. writing data: e.g.
   `fileout << x ;`
5. close file via method `close`:

   `fileout.close() ;`

Alternatively (Unix): Use cout and redirection operator > or >> of the shell:
`./program > output.txt`

Classes – Example: writing/reading files II

By including the `<fstream>` library, one can also read from a file

Input from a file

```
char line[132] ;
ifstream filein ; // create ifstream object
filein.open("data.txt") ; // open the file
while ( filein.good() ) {
    filein.getline(line,132) ; // read in line;
                               // use buffer size (132)
    x[i] = atof(line) ;        // read into float array
}
```

The method `good()` checks, whether the end of file (EOF) is reached or an error occured.

Templates I

Templates allow to create universal definitions of certain structures. The final realization for a specific data type is done by the compiler.

Function templates

```
template <class T> // instead of class also typename
T sqr (const T &x) {
 return x * x ; }
```

The keyword `template` and the angle brackets < > signalize the compiler that `T` is a template parameter. The compiler will process this function if a specific data type is invoked by a function call, e.g.,

```
double w = 3.34 ; int k = 2 ;
cout << sqr(w) << " " << sqr(k) ;
```

Templates II

Moreover, templates can be used to create structs/classes. For example, the class `complex` of the standard C++ library (`#include <complex>`) is realized as template class:

Class templates

```
template <class T>
class std::complex {
   T re, im ;
 public:
     ...
   T real() const return re ;
}
```

Therefore, the member variables `re` and `im` can be arbitrary (numerical) data types.

Typ definitions via typedef

By using `typedef` *datatype aliasname* one can declare new names for data types:

```
typedef unsigned long   large ;
typedef char*  pchar ;
typedef std:complex<double>  complex_d ;
```

These new type names can then be used for variable declarations:

```
large  mmm ;
pchar  Bpoint ;
complex_d  z = complex_d (1.2, 3.4) ;
```

In the last example, the constructor for the class template `complex` gets the same name as the variable through the `typedef` command.

Exception handling – exceptions I

A major strength of C++ is the ability to handle runtime errors, so called exceptions:

Throwing exceptions: `try` – `throw` – `catch`

```
 try {
    cin >> x ;
    if ( x < 0.) throw "Negative value!" ;
    y  = g(x) ;
 }
 catch (char* info) { // catch exception from try block
    cout << "Program stops, because of: << info << endl ;
    exit (1) ;
 }
double g (double x) {
  if (x > 1000.) throw "x too large!" ; ... }
```

Exception handling – exceptions II

`try { ...}`

- within a `try` block an arbitrary exception can be thrown

`throw` *e* ;

- throw an exception *e*
- the data type of *e* is used to identify to the corresponding `catch` block to which the program will jump
- exceptions can be intrinsic or self defined data types

Exception handling – exceptions III

`catch ( type e ) { ...}`

- after a `try` one or more `catch` blocks can be defined
- from the data type of *e* the first matching `catch` block will be selected
- any exception can be catched by `catch (...)`
- if after a `try` no matching `catch` block is found, the search is continued in the next higher call level
- if no matching block at all is found, the `terminate` function is called; its default is to call `abort`

Reading arguments from program call

Sometimes it is more convenient to pass the parameters the program nees directly at the call of the program, e.g,

`./rstarcalc 3.5 35.3`

this can be realized with help of the library `stdlib.h`

Read an integer number from command line call

```
#include "stdlib.h"
int main (int narg, char *args[]) {
  int k ;
  // convert char array to integer
  if (narg > 1) k = atoi(args[1]) ;
}
```

- if the string cannot be converted to `int`, the returned value is 0
- there exist also `atol` and `atof` for conversion to `long` and `float`

Summary

Common mistakes in C/C++:

- forgotten semicolon `;`
- wrong dimensioning/access to arrays
  `int m[4] ; imax = m[4] ;` → `imax = m[3] ;`
- wrong data type in instructions / function calls
  `float x ; ... switch (x)`
  `void swap (int *i, int *j) ; ... swap(n,m) ;`
- confusing assignment operator `=` with the equality operator `==`
  `if(i = j)` → `if(i == j)`
- forgotten function parenthesis for functions without parameters
  `clear ;` → `clear();`
- ambiguous expressions
  `if (i == 0 && ++j == 1)`
  no increment of `j`, if `i` $\neq 0$

Some recommendations I

- use always(!) the `.` for floating point literals: `x = 1./3.` instead of `x = 1/3`
- whitespace is for free $\rightarrow$ use it extensively for structuring your source code (indentation, blank lines)
- comment so that you(!) understand your source code in a year
- use self-explaining variable names, e.g., `Teff` instead of `T` (think about searching for this variable in the editor)
- use integer loop variables:

```
for (int i = 1; i < n ; ++i) {
 x = x + 0.1 ; ... }
```

  instead of

```
for (float x = 0.; x < 100. ; x = x + 0.1) {... }
```

- take special care of user input, usually: $t_{\text{input}} \ll t_{\text{calc}}$, so exception catching for input is never wasted computing time