# 6. Control Statements II

Visibility, Local Variables, While Statement, Do Statement, Jump Statements

# Visibility

Declaration in a block is not *visible* outside of the block.

```
int main()
{
    {
        int i = 2;
    }
    std::cout << i; // Error:  undeclared name
    return 0;
}
```

main block

block

„Blickrichtung“

# Control Statement defines Block

In this respect, statements behave like blocks.

```
int main()
{
block | for (unsigned int i = 0; i < 10; ++i)
      |     s += i;
    std::cout << i; // Error:  undeclared name
    return 0;
}
```

# Scope of a Declaration

*Potential* scope: from declaration until end of the part that contains the declaration.

**in the block**

```
{
    ...
    int i = 2;
    ...
}
```

scope

**in function body**

```
int main() {
    ...
    int i = 2;
    ...
    return 0;
}
```

scope

**in control statement**

```
for (int i = 0; i < 10; ++i) {s += i; ... }
```

scope

# Scope of a Declaration

*Real* scope = potential scope minus potential scopes of declarations of symbols with the same name

```
int main()
{
  int i = 2;
  for (int i = 0; i < 5; ++i)
     // outputs 0,1,2,3,4
     std::cout << i;
   // outputs 2
   std::cout << i;
  return 0;
}
```

scope of i in main

$i_2$ in for

# Automatic Storage Duration

Local Variables (declaration in block)

- are (re-)created each time their declaration is reached
  - memory address is assigned (allocation)
  - potential initialization is executed
- are deallocated at the end of their declarative region (memory is released, address becomes invalid)

# Local Variables

```
int main()
{
    int i = 5;
    for (int j = 0; j < 5; ++j) {
        std::cout << ++i; // outputs 6, 7, 8, 9, 10
        int k = 2;
        std::cout << --k; // outputs 1, 1, 1, 1, 1
    }
}
```

Local variables (declaration in a block) have *automatic storage duration*.

# `while` Statement

```
while (condition)
  statement
```

- *statement*: arbitrary statement, body of the **`while`** statement.
- *condition*: convertible to **`bool`**.

# `while` Statement

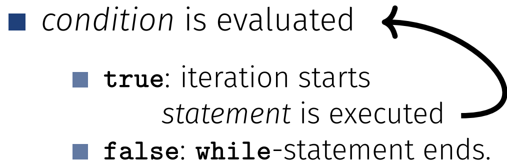
```
while (condition)
  statement
```

is equivalent to

```
for (; condition; )
  statement
```

# `while`-Statement: Semantics

```
while (expression)
  statement
```



# `while`-statement: why?

- In a **`for`**-statement, the expression often provides the progress ("counting loop")

```
for (unsigned int i = 1; i <= n; ++i)
    s += i;
```

- If the progress is not as simple, **`while`** can be more readable.

# Example: The Collatz-Sequence $(n \in \mathbb{N})$

- $n_0 = n$
- $n_i = \begin{cases} \frac{n_{i-1}}{2} & \text{, if } n_{i-1} \text{ even} \\ 3n_{i-1} + 1 & \text{, if } n_{i-1} \text{ odd} \end{cases}, i \geq 1.$

n=5: 5, 16, 8, 4, 2, 1, 4, 2, 1, ... (repetition at 1)

# The Collatz Sequence in C++

```cpp
// Program collatz.cpp. Computes the Collatz sequence of a number n.

#include <iostream>

int main() {
  // Input
  std::cout << "Compute the Collatz sequence for n =? ";
  unsigned int n;
  std::cin >> n;

  // Iteration
  while (n > 1) {
    if (n % 2 == 0) n = n / 2;
    else n = 3 * n + 1;
    std::cout << n << " ";
  }
  std::cout << "\n";

  return 0;
}
```

# The Collatz Sequence in C++

```
n = 27:
82, 41, 124, 62, 31, 94, 47, 142, 71, 214, 107, 322, 161, 484, 242,
121, 364, 182, 91, 274, 137, 412, 206, 103, 310, 155, 466, 233, 700,
350, 175, 526, 263, 790, 395, 1186, 593, 1780, 890, 445, 1336, 668,
334, 167, 502, 251, 754, 377, 1132, 566, 283, 850, 425, 1276, 638,
319, 958, 479, 1438, 719, 2158, 1079, 3238, 1619, 4858, 2429, 7288,
3644, 1822, 911, 2734, 1367, 4102, 2051, 6154, 3077, 9232, 4616,
2308, 1154, 577, 1732, 866, 433, 1300, 650, 325, 976, 488, 244, 122,
61, 184, 92, 46, 23, 70, 35, 106, 53, 160, 80, 40, 20, 10, 5, 16, 8,
4, 2, 1
```

# The Collatz-Sequence

Does $1$ occur for each $n$?

- It is conjectured, but nobody can prove it!
- If not, then the **`while`**-statement for computing the Collatz-sequence can theoretically be an endless loop for some $n$.

# `do` Statement

```
do
  statement
while (condition);
```

- *statement*: arbitrary statement, body of the **`do`** statement.
- *condition*: convertible to **`bool`**.

# `do` Statement

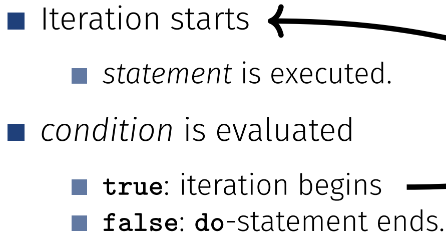
```
do
  statement
while (condition);
```

is equivalent to

```
statement
while (condition)
  statement
```

# `do`-Statement: Semantics

```
do
  statement
while (condition);
```



- Iteration starts
  - *statement* is executed.
- *condition* is evaluated
  - **`true`**: iteration begins
  - **`false`**: **`do`**-statement ends.

# do-Statement: Example Calculator

Sum up integers (if 0 then stop):

```
int a;     // next input value
int s = 0; // sum of values so far
do {
    std::cout << "next number =? ";
    std::cin >> a;
    s += a;
    std::cout << "sum = " << s << "\n";
} while (a != 0);
```

# Conclusion

- Selection (conditional *branches*)
  - **`if`** and **`if-else`**-statement
- Iteration (conditional *jumps*)
  - **`for`**-statement
  - **`while`**-statement
  - **`do`**-statement
- Blocks and scope of declarations

# Jump Statements

- `break`;
- `continue`;

# `break`-Statement

```
break;
```

- Immediately leave the enclosing iteration statement
- useful in order to be able to break a loop “in the middle” [5]

[5] and indispensible for switch-statements

# Calculator with `break`

Sum up integers (if 0 then stop)

```
int a;
int s = 0;
do {
    std::cout << "next number =? ";
    std::cin >> a;
    s += a; /* irrelevant in last iteration */
    std::cout << "sum = " << s << "\n";
} while (a != 0);
```

# Calculator with `break`

Suppress irrelevant addition of 0:

```
int a;
int s = 0;
do {
    std::cout << "next number =? ";
    std::cin >> a;
    if (a == 0) break; // exit loop in the middle
    s += a;
    std::cout << "sum = " << s << "\n";
} while (a != 0)
```

# Calculator with `break`

Equivalent and yet more simple:

```
int a;
int s = 0;
for (;;) {
    std::cout << "next number =? ";
    std::cin >> a;
    if (a == 0) break; // exit loop in the middle
    s += a;
    std::cout << "sum = " << s << "\n";
}
```

# Calculator *without* `break`

Version without `break` evaluates `a != 0` twice (and requires an additional block).

```
int a = 1;
int s = 0;
for (; a != 0; ) {
    std::cout << "next number =? ";
    std::cin >> a;
    if (a != 0) {
        s += a;
        std::cout << "sum = " << s << "\n";
    }
}
```

# `continue`-Statement

```
continue;
```

- Jump over the rest of the body of the enclosing iteration statement
- Iteration statement is *not* left.

# `break` and `continue` in practice

- Advantage: Can avoid nested `if-else`blocks (or complex disjunctions)
- But they result in additional jumps and thus potentially complicate the control flow
- Their use is thus controversial, and should be carefully considered

# Calculator with `continue`

Ignore negative input:

```
for (;;) {
    std::cout << "next number =? ";
    std::cin >> a;
    if (a < 0) continue; // jump to }
    if (a == 0) break;
    s += a;
    std::cout << "sum = " << s << "\n";
}
```

# Equivalence of Iteration Statements

We have seen:

- `while` and `do` can be simulated with `for`

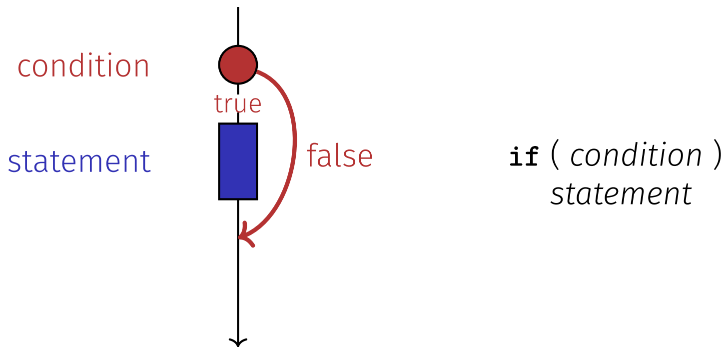
It even holds:

- The three iteration statements provide the same “expressiveness” (lecture notes)
- Not so simple if a `continue` is used

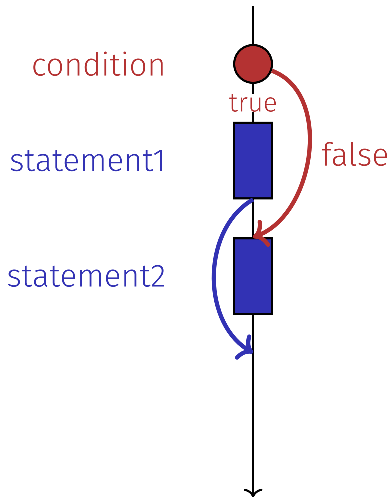
# Control Flow

Order of the (repeated) execution of statements

- generally from top to bottom...
- ...except in selection and iteration statements



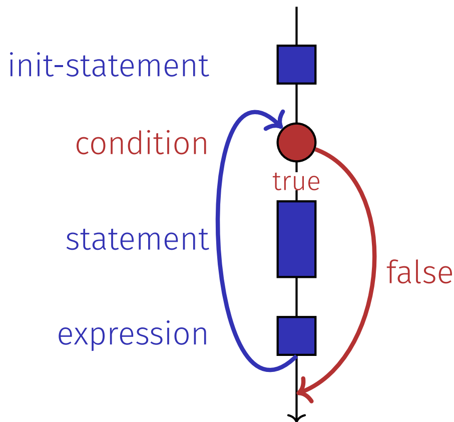
# Control Flow `if else`



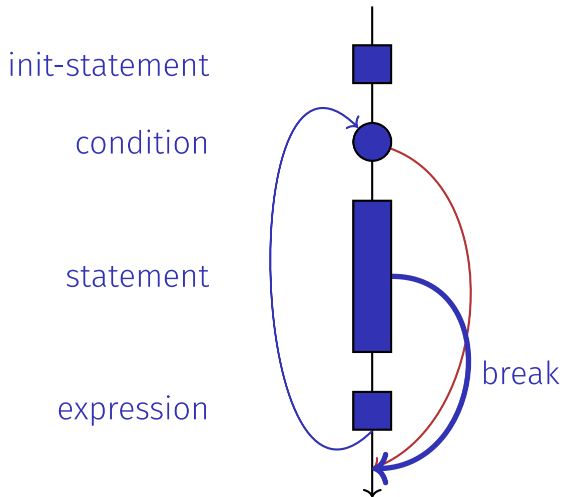

**if** ( *condition* )
    *statement1*
else
    *statement2*

# Control Flow `for`

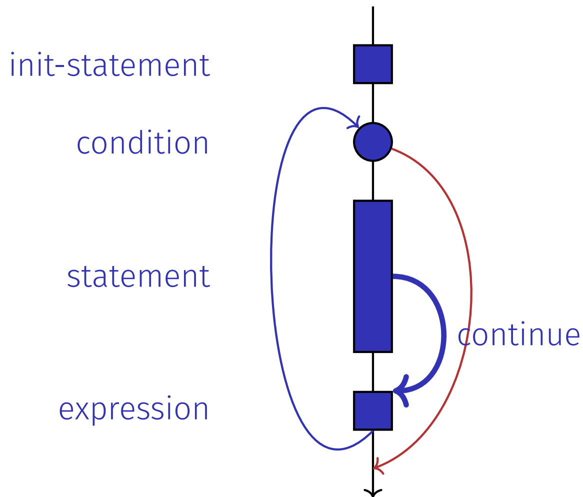
`for` ( *init statement*  *condition* `;` *expression* )
   *statement*



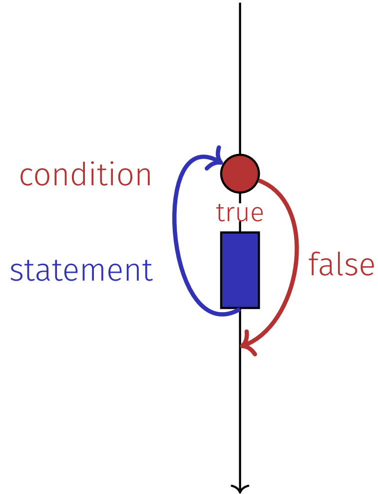
# Control Flow `break` in for



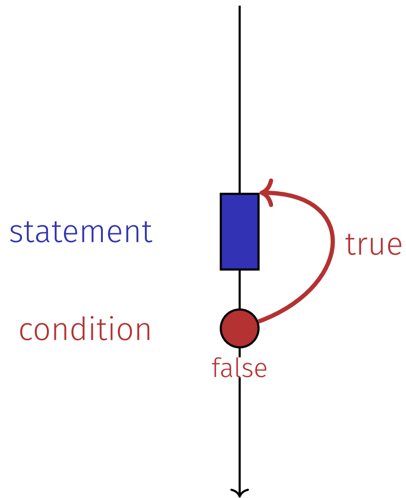
# Control Flow `continue` in for



# Control Flow `while`



# Control Flow `do while`



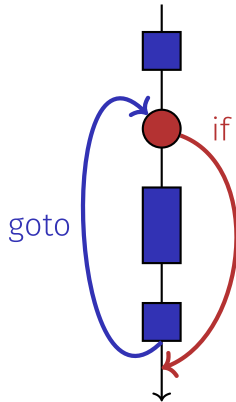
# Control Flow: the Good old Times?

## Observation

Actually, we only need **`if`** and jumps to arbitrary places in the program (**`goto`**).

Languages based on them:

- Machine Language
- Assembler (“higher” machine language)
- BASIC, the first programming language for the general public (1964)



# BASIC and home computers...

...allowed a whole generation of young adults to program.

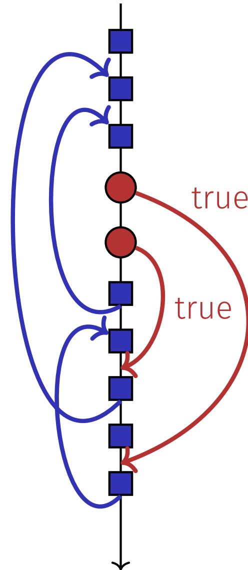
Home-Computer Commodore C64 (1982)

http://de.wikipedia.org/wiki/Commodore_64

# Spaghetti-Code with `goto`

Output of of ???????????all prime numbers using the programming language BASIC:

```
10  N=2
20  D=1
30  D=D+1
40  IF  N=D  GOTO  100
50  IF  N/D  =  INT(N/D)  GOTO  70
60  GOTO  30
70  N=N+1
80  GOTO  20
100  PRINT  N
110  GOTO  70
```



# The “right” Iteration Statement

Goals: readability, conciseness, in particular

- few statements
- few lines of code
- simple control flow
- simple expressions

Often not all goals can be achieved simultaneously.

# Odd Numbers in $\{0, \ldots, 100\}$

First (correct) attempt:

```
for (unsigned int i = 0; i < 100; ++i) {
    if (i % 2 == 0)
        continue;
    std::cout << i << "\n";
}
```

# Odd Numbers in $\{0, \ldots, 100\}$

**Less** statements, **less** lines:

```
for (unsigned int i = 0; i < 100; ++i) {
    if (i % 2 != 0)
        std::cout << i << "\n";
}
```

# Odd Numbers in $\{0, \ldots, 100\}$

**Less** statements, **simpler** control flow:

```
for (unsigned int i = 1; i < 100; i += 2)
    std::cout << i << "\n";
```

This is the “right” iteration statement

# Jump Statements

- implement unconditional jumps.
- are useful, such as **`while`** and **`do`** but not indispensible
- should be used with care: only where the control flow is *simplified* instead of making it *more complicated*

# Outputting Grades

1. Functional requirement:

$$
\begin{aligned}
6 &\rightarrow \texttt{"Excellent ...  You passed!"} \\
5, 4 &\rightarrow \texttt{"You passed!"} \\
3 &\rightarrow \texttt{"Close, but ...  You failed!"} \\
2, 1 &\rightarrow \texttt{"You failed!"} \\
\textit{otherwise} &\rightarrow \texttt{"Error!"}
\end{aligned}
$$

2. Moreover: Avoid duplication of text and code

# Outputting Grades with `if` Statements

```
int grade;
...
if (grade == 6) std::cout << "Excellent ... ";
if (4 <= grade && grade <= 6) {
    std::cout << "You passed!";
} else if (1 <= grade && grade < 4) {
    if (grade == 3) std::cout << "Close, but ... ";
    std::cout << "You failed!";
} else std::cout << "Error!";
```

Disadvantage: Control flow – and thus program behaviour – not quite obvious

# Outputting Grades with `switch` Statement

```
switch (grade) {
  case 6: std::cout << "Excellent ... ";
  case 5:
  case 4: std::cout << "You passed!";
    break;
  case 3: std::cout << "Close, but ... ";
  case 2:
  case 1: std::cout << "You failed!";
    break;
  default: std::cout << "Error!";
}
```

- `switch (grade) {` — Jump to matching `case`
- `case 6` → `case 4` — Fall-through
- first `break;` — Exit `switch`
- `case 3` → `case 1` — Fall-through
- second `break;` — Exit `switch`
- `default:` — In all other cases

Advantage: Control flow clearly recognisable

# The `switch`-Statement

```
switch (expression)
  statement
```

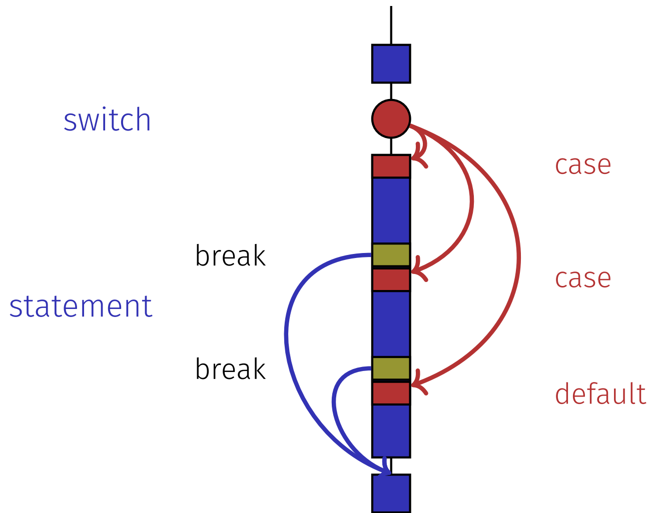
- *expression*: Expression, convertible to integral type
- *statement* : arbitrary statemet, in which **`case`** and **`default`**-lables are permitted, **`break`** has a special meaning.
- Use of fall-through property is controversial and should be carefully considered (corresponding compiler warning can be enabled)

# Semantics of the `switch`-statement

> `switch` (*expression*)
> *statement*

- `expression` is evaluated.
- If `statement` contains a `case`-label with (constant) value of `condition`, then jump there
- otherwise jump to the `default`-lable, if available. If not, jump over `statement`.
- The `break` statement ends the `switch`-statement.

# Control Flow `switch`



# 7. Floating-point Numbers I

Types `float` and `double`; Mixed Expressions and Conversion; Holes in the Value Range

# “Proper” Calculation

```
// Program: fahrenheit_float.cpp
// Convert temperatures from Celsius to Fahrenheit.

#include <iostream>

int main() {
  // Input
  std::cout << "Temperature in degrees Celsius =? ";
  float celsius;
  std::cin >> celsius;

  // Computation and output
  std::cout << celsius << " degrees Celsius are "
            << 9 * celsius / 5 + 32 << " degrees Fahrenheit.\n";
  return 0;
}
```

# Fixed-point numbers

- fixed number of integer places (e.g. 7)
- fixed number of decimal places (e.g. 3)

```
0.0824 = 0000000.082
```
← third place truncated

Disadvantages

- Value range is getting *even* smaller than for integers.
- Representability depends on the position of the decimal point.

# Floating-point numbers

- Observation: same number, different representations with varying "efficiency", e.g.

$$\begin{aligned} 0.0824 &= 0.00824 \cdot 10^{1} &&= 0.824 \cdot 10^{-1} \\ &= 8.24 \cdot 10^{-2} &&= 824 \cdot 10^{-4} \end{aligned}$$

  Number of *significant digits* remains constant

- Floating-point number representation thus:
  - Fixed number of significant places (e.g. 10),
  - Plus position of the decimal point via exponent
  - Number is $\mathit{Mantissa} \times 10^{\mathit{Exponent}}$

# Types `float` and `double`

- are the fundamental C++ types for floating point numbers
- approximate the field of real numbers $(\mathbb{R}, +, \times)$ from mathematics
- have a big value range, sufficient for many applications:
  - **`float`**: approx. 7 digits, exponent up to $\pm 38$
  - **`double`**: approx. 15 digits, exponent up to $\pm 308$
- are fast on most computers (hardware support)

# Arithmetic Operators

Analogous to `int`, but ...

- Division operator `/` models a “proper” division (real-valued, not integer)
- No modulo operator, i.e. no `%`

# Literals

are different from integers by providing

- decimal point

`1.0` : type **`double`**, value $1$

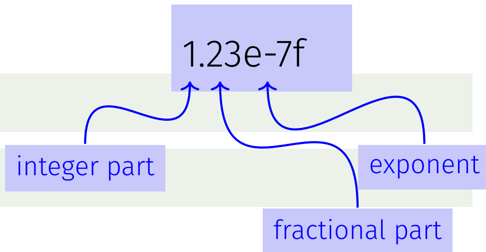
`1.27f` : type **`float`**, value $1.27$

- and / or exponent.

`1e3` : type **`double`**, value $1000$

`1.23e-7` : type **`double`**, value $1.23 \cdot 10^{-7}$

`1.23e-7f` : type **`float`**, value $1.23 \cdot 10^{-7}$



# Computing with `float`: Example

Approximating the Euler-Number

$$e = \sum_{i=0}^{\infty} \frac{1}{i!} \approx 2.71828\ldots$$

using the first 10 terms.

# Computing with `float`: Euler Number

```cpp
std::cout << "Approximating the Euler number... \n";

// values for i-th iteration, initialized for i = 0
float t = 1.0f; // term 1/i!
float e = 1.0f; // i-th approximation of e

// iteration 1, ..., n
for (unsigned int i = 1; i < 10; ++i) {
    t /= i;    // 1/(i-1)! -> 1/i!
    e += t;
    std::cout << "Value after term " << i << ": "
              << e << "\n";
}
```

# Computing with `float`: Euler Number

```
Value after term 1: 2
Value after term 2: 2.5
Value after term 3: 2.66667
Value after term 4: 2.70833
Value after term 5: 2.71667
Value after term 6: 2.71806
Value after term 7: 2.71825
Value after term 8: 2.71828
Value after term 9: 2.71828
```

# Mixed Expressions, Conversion

- Floating point numbers are more general than integers.
- In mixed expressions integers are converted to floating point numbers.

```
9 * celsius / 5  + 32
```

# Holes in the value range

```
float n1;
std::cout << "First number  =? ";
std::cin >> n1;

float n2;
std::cout << "Second number =? ";
std::cin >> n2;

float d;
std::cout << "Their difference =? ";
std::cin >> d;

std::cout << "Computed difference - input difference = "
          << n1 - n2 - d << "\n";
```

input 1.1

input 1.0

input 0.1

output 2.23517e-8

What is going on here?

# Value range

Integer Types:

- Over- and Underflow relatively frequent, but ...
- the value range is contiguous (no holes): $\mathbb{Z}$ is “discrete”.

Floating point types:

- Overflow and Underflow seldom, but ...
- there are holes: $\mathbb{R}$ is “continuous”.