# Programming using C++

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2022-02-05

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# Why C++?

- C++ shares similar syntax with many other programming languages
  - Java, JavaScript, C#, Objective C, PHP, etc.
- Centered around important CS concepts
  - Data types, control structures, object-oriented programming
- Wide range of applications and can be run in different environments
  - Servers, operating systems, games, embedded systems, etc.
  - C++ standard provides a portable interface. Programs can be compiled into executable for different systems.

# Why C++ for competitive programming?

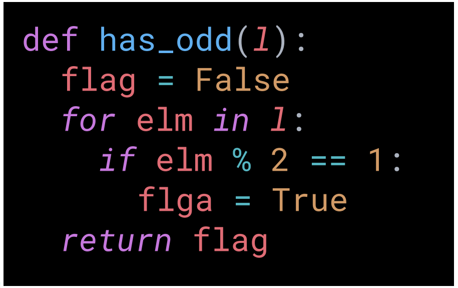
- C++ programs runs very fast
  - In many contests, problems are not guaranteed to be solvable by all languages
    - **IOI**: “The ISC and ITC do not want to put a guaranteed percentage on points that could be gained by a second class language, or have different time limits based on language.”
    - **Code Jam**: “... it is not guaranteed that any problem can be solved in any language; ... Just as in everyday software engineering, part of the contest is using the right tool for each job!”
    - **HKOI 2022/23**:

      Heat event: **C++20** will be the only programming language

      Final event: **C++20** will be the only first class programming language

# Why C++ for competitive programming?

- C++ programs runs very fast
    - In many contests, problems are not guaranteed to be solvable by all languages
- C++ STL comes with useful algorithms and data structures
    - Sorting, binary search, stack, heap (priority_queue), binary search tree (set, map), etc.
- C++ programs are easy to debug
    - Compilation step can help uncover bugs



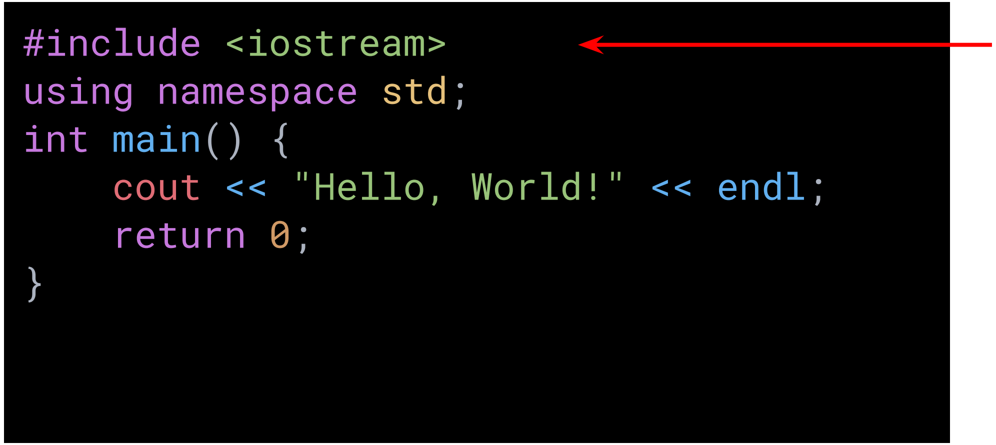
```
def has_odd(l):
  flag = False
  for elm in l:
    if elm % 2 == 1:
      flga = True
  return flag
```

This Python program would not even cause runtime error

# C++ standard

- Starting from 2011, 3 years a standard (C++11, C++14, ...)
  - The newest standard is C++20
  - In most cases, new standards are backward compatible
  - g++ flag: `-std=c++11`, `-std=c++14`, ...
- Different contests may support different standards
  - HKOI Online Judge, codeforces supports C++20
  - IOI, APIO supports C++17
  - NOI supports C++14
- Today I am going to teach you how to write **good** C++ programs
  - We will focus on making the best use of **new** C++ features
  - To learn more about data types and C++ language, you may refer to the 2019 slides :
    - Introduction to C++
    - Data Processing

# Basic program structure



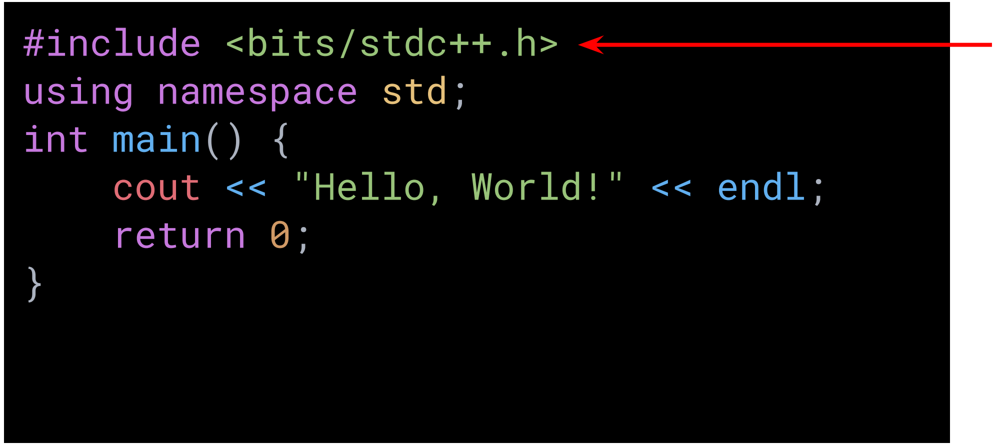
```
#include <iostream>
using namespace std;
int main() {
    cout << "Hello, World!" << endl;
    return 0;
}
```

Include library headers

`<iostream>` provides input and output functionality (`cout` and `endl` in this example)

#include <iostream>

# Basic program structure



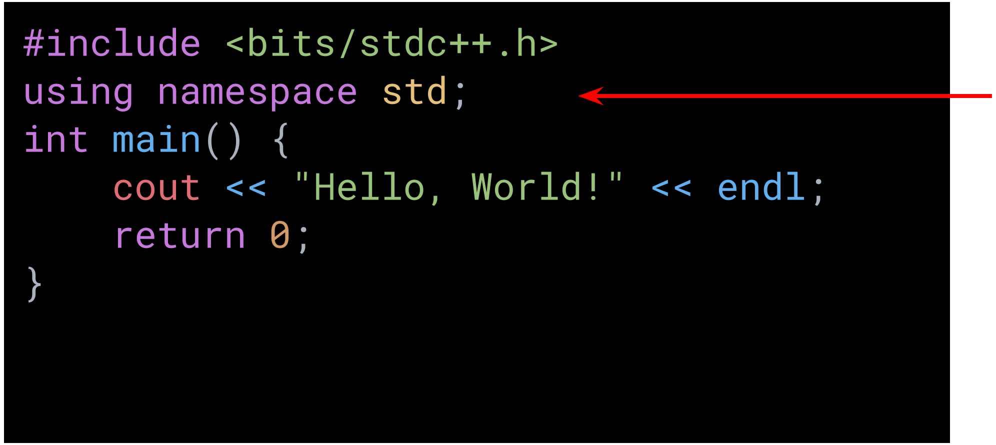
```cpp
#include <bits/stdc++.h>
using namespace std;
int main() {
    cout << "Hello, World!" << endl;
    return 0;
}
```

When using GCC C++ compiler, `<bits/stdc++.h>` provides most functions needed for competitive programming

- Shorter header
- Avoid compilation errors caused by missing header, especially in contests with no feedback

<bits/stdc++.h>

# Basic program structure



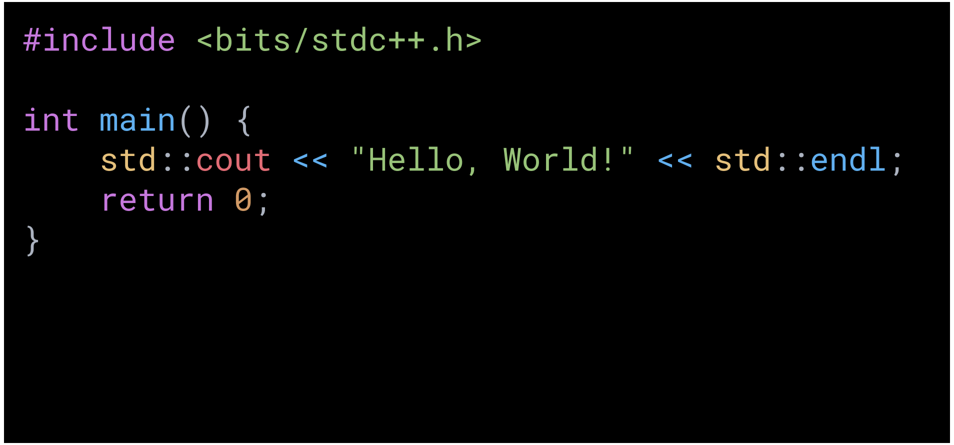
```
#include <bits/stdc++.h>
using namespace std;
int main() {
    cout << "Hello, World!" << endl;
    return 0;
}
```

This line is to “move” everything in the `std` namespace into our program

- Pros: No need to type `std::` prefix
- Cons: Program may not be forward compatible

namespace

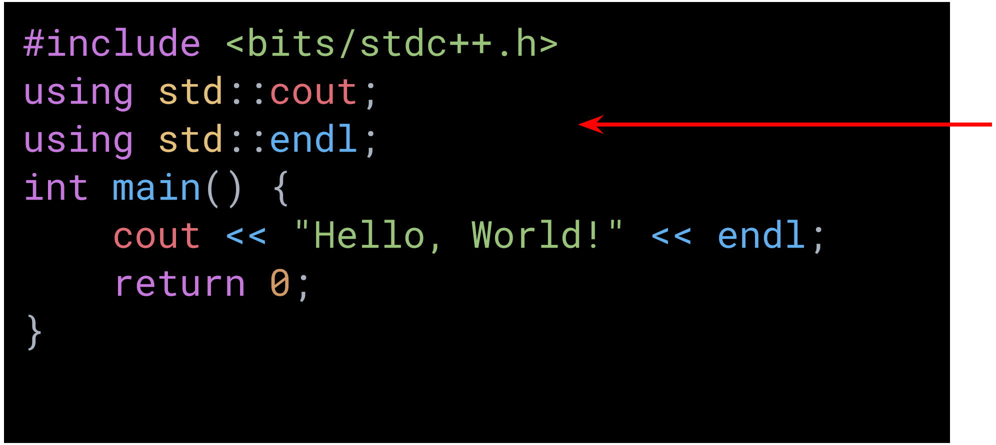
# Basic program structure



```cpp
#include <bits/stdc++.h>

int main() {
    std::cout << "Hello, World!" << std::endl;
    return 0;
}
```

Example without
`using namespace std;`

# Basic program structure



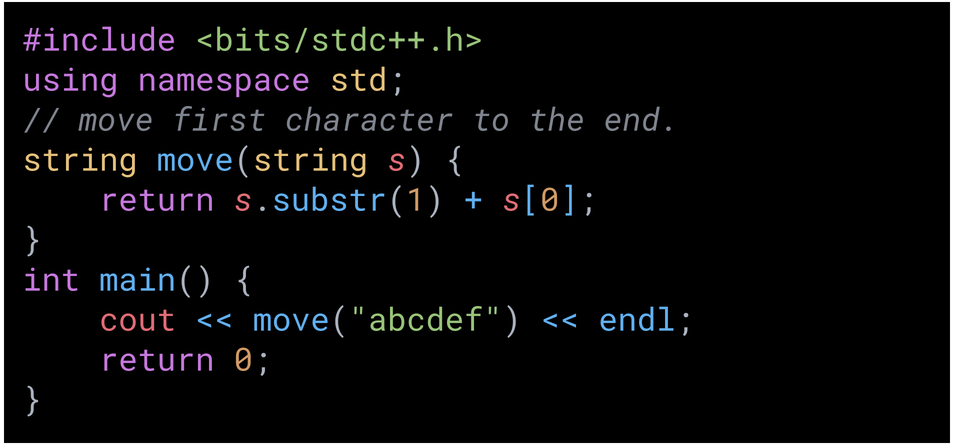
```cpp
#include <bits/stdc++.h>
using std::cout;
using std::endl;
int main() {
    cout << "Hello, World!" << endl;
    return 0;
}
```

Bring in specific symbols

This won’t have the forward compatibility issue

using declaration

# Forward compatibility issue



```cpp
#include <bits/stdc++.h>
using namespace std;
// move first character to the end.
string move(string s) {
    return s.substr(1) + s[0];
}
int main() {
    cout << move("abcdef") << endl;
    return 0;
}
```

```
g++ -std=c++03 program.cpp -o program
```

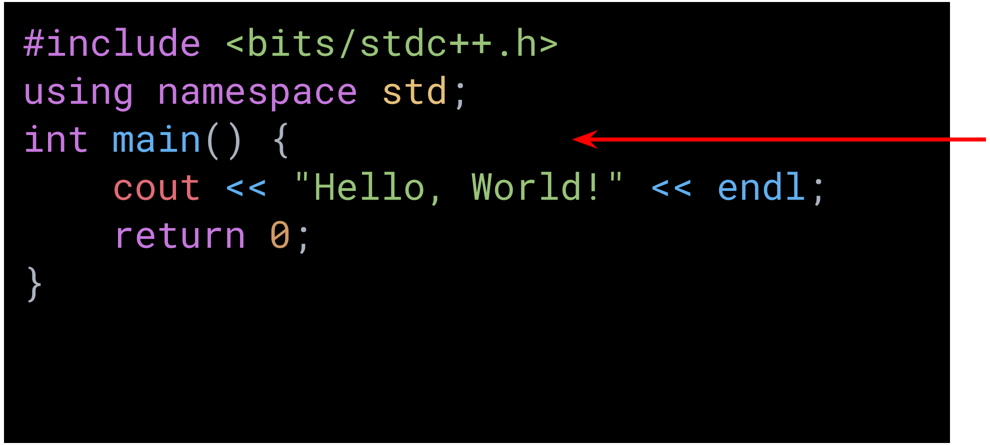
Output: bcdefa

```
g++ -std=c++11 program.cpp -o program
```

Output: abcdef

move

# Basic program structure



```cpp
#include <bits/stdc++.h>
using namespace std;
int main() {
    cout << "Hello, World!" << endl;
    return 0;
}
```

This is the main program

Note that the return type is `int`

Main function

# Basic program structure

```
#include <bits/stdc++.h>
using namespace std;
int main() {
    cout << "Hello, World!" << endl;
    return 0;
}
```

```
(windows) a.exe && b.exe
(linux)   ./a && ./b
```

A return code of **0** indicates that the program ended successfully

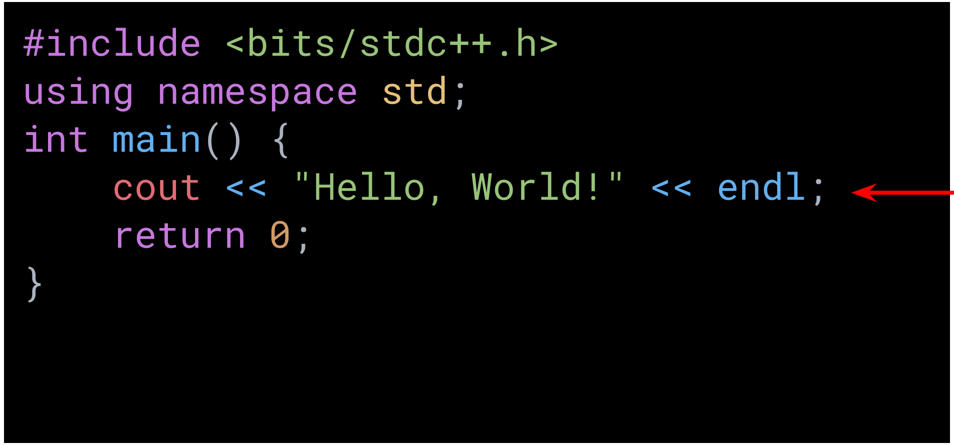
Other numbers can be used to indicate that there is some warning / error

You can use && in the console to chain commands. In this example, program B runs only if program A returns 0

`return 0;` is optional

Main function

# Basic program structure



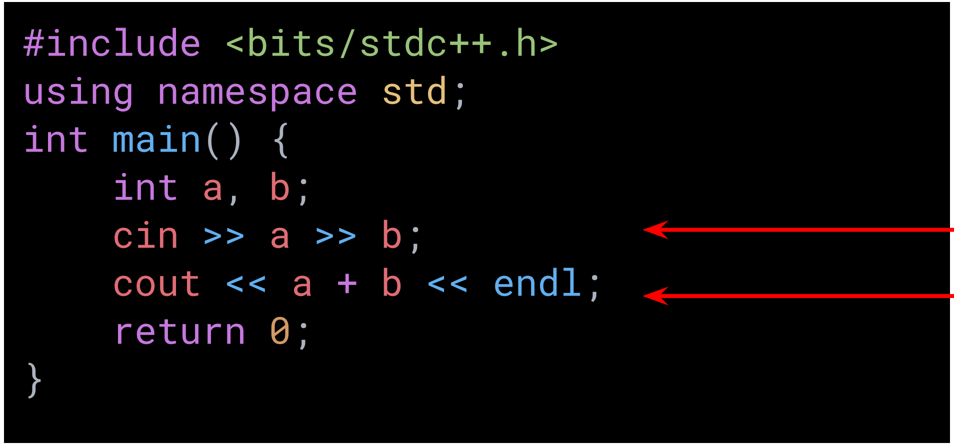
```cpp
#include <bits/stdc++.h>
using namespace std;
int main() {
    cout << "Hello, World!" << endl;
    return 0;
}
```

Send “Hello, World!” and line break to the output stream

`endl` also flushes the stream (useful for interactive tasks)

cout endl

# Input and output



```
#include <bits/stdc++.h>
using namespace std;
int main() {
    int a, b;
    cin >> a >> b;
    cout << a + b << endl;
    return 0;
}
```

Read two numbers a and b

Output their sum

cin cout

# Integers

int: 32 bits in most systems

long long: 64 bits in most systems

```
int main() {
    cout << numeric_limits<int>::min() << endl;
    cout << numeric_limits<int>::max() << endl;
    cout << numeric_limits<long long>::min() << endl;
    cout << numeric_limits<long long>::max() << endl;
    return 0;
}
```

```
Input
```

```
Output

-2147483648
2147483647
-9223372036854775808
9223372036854775807
```

# Arithmetic operators

| name | syntax | name | syntax |
|---|---|---|---|
| addition | a + b | bitwise not | ~a |
| subtraction | a - b | bitwise and | a & b |
| multiplication | a * b | bitwise or | a \| b |
| division | a / b | bitwise xor | a ^ b |
| modulo | a % b | bitwise left shift | a << b |
| | | bitwise right shift | a >> b |

To change the variable itself, you may also use a += b, a -= b, ...

For self increment / decrement, you may use ++ / --

- x++: return the original **value** of x, then increase x by 1
- ++x: increase x by 1, then return the **reference** of x

Arithmetic operators

# Floating point numbers

float: 32 bits

double: 64 bits

long double: 128 bits

Supported operators: +, -, *, /

# Division

In C++, we use / for both integer division and floating point division

If both dividend and divisor are integer types, integer division is performed

If any of the dividend and divisor is a floating point type, floating point division is performed

```
int main() {
    cout << 5 / 2 << endl;
    cout << 5.0 / 2 << endl;
    cout << 5 / 2.0 << endl;
    return 0;
}
```

```
Input
```

```
Output

2
2.5
2.5
```

# Output floating point numbers

By default, C++ output stream outputs large floating point numbers in scientific notation.

Use `cout << fixed` to output in fixed decimal point

Use `cout << setprecision(x)` to output in x decimal points (default is 6)

```
int main() {
    double pi = acos(-1);
    cout << pi << endl;
    cout << fixed << pi << endl;
    cout << setprecision(9) << pi << endl;
    return 0;
}
```

```
Input
```

```
Output

3.14159
3.141593
3.141592654
```

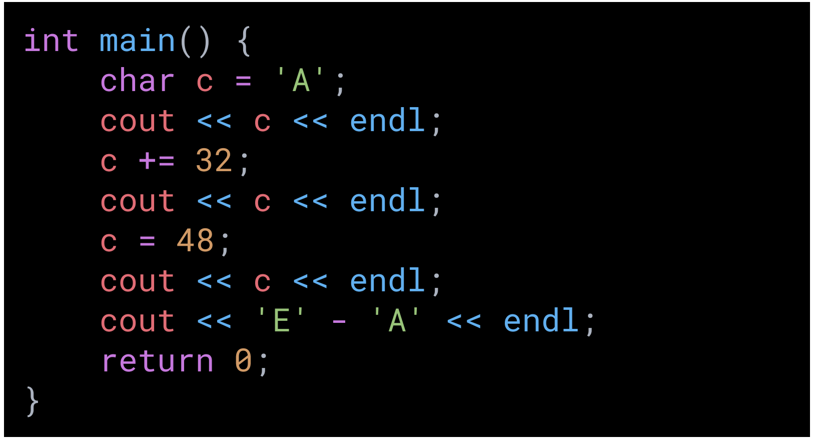
fixed setprecision

# Characters

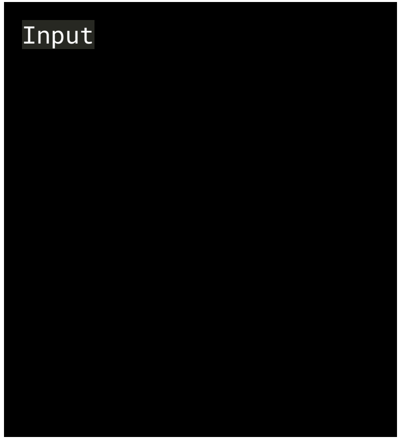
A 8-bit integer type

You can do arithmetic directly on it

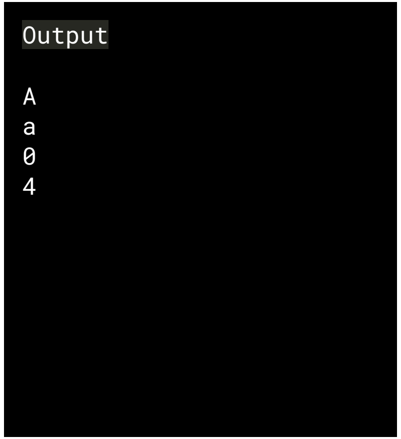
In C++, we use single quote for characters and double quote for strings



```
int main() {
    char c = 'A';
    cout << c << endl;
    c += 32;
    cout << c << endl;
    c = 48;
    cout << c << endl;
    cout << 'E' - 'A' << endl;
    return 0;
}
```



```
Input
```



```
Output

A
a
0
4
```

# Boolean

Only 2 values: `true` and `false`

Logical operators:

| name | syntax |
|---|---|
| negation | `!a // not a` |
| and | `a && b // a and b` |
| inclusive or | `a || b // a or b` |

Logical operators

# Comparison operators

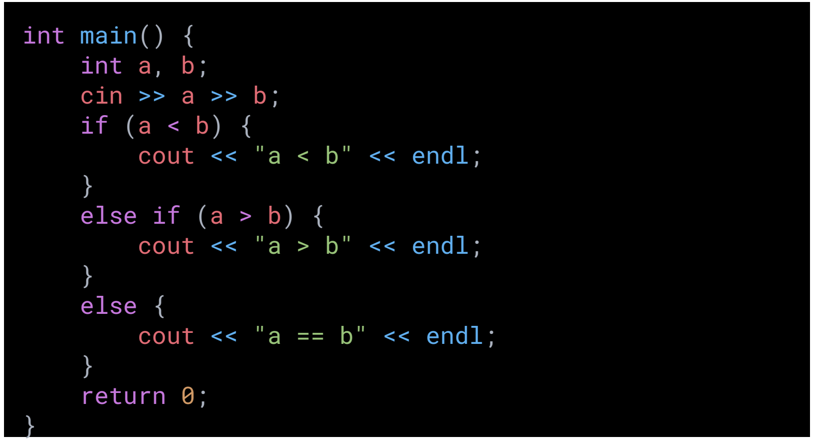
Compare two variables, return `bool`

| name | syntax | name | syntax |
|---|---|---|---|
| equal to | `a == b` | less than or equal to | `a <= b` |
| not equal to | `a != b` | greater than or equal to | `a >= b` |
| less than | `a < b` | three-way comparison (since C++20, does not return `bool`) | `a <=> b` |
| greater than | `a > b` | | |

Comparison operators

# If statement

You can omit the bracket if there is only one statement



```
int main() {
    int a, b;
    cin >> a >> b;
    if (a < b) {
        cout << "a < b" << endl;
    }
    else if (a > b) {
        cout << "a > b" << endl;
    }
    else {
        cout << "a == b" << endl;
    }
    return 0;
}
```

```
Input

3 3
```

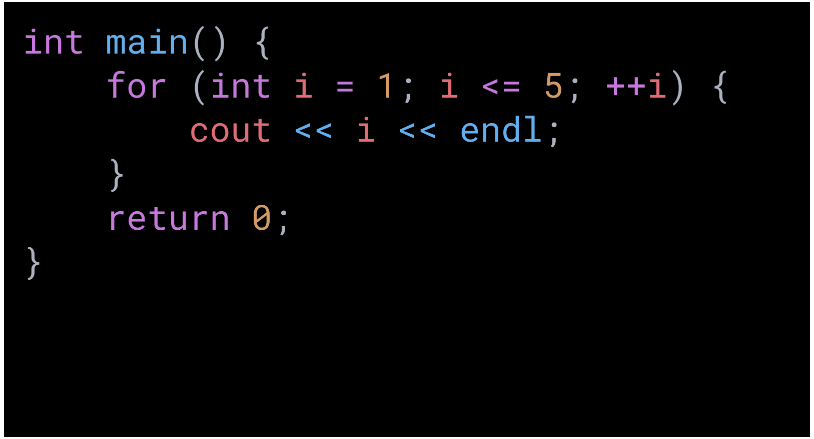
```
Output

a == b
```

[if statement]

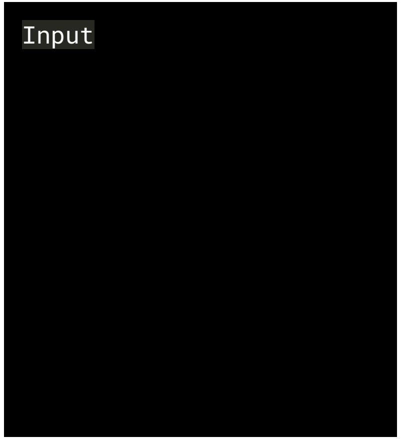
# For loop

Syntax: `for (initial; condition; step)`

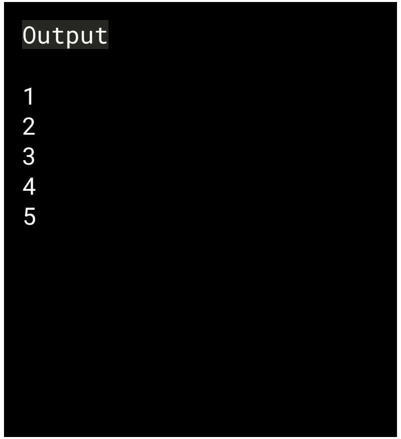
You can omit the bracket if there is only one statement



```
int main() {
    for (int i = 1; i <= 5; ++i) {
        cout << i << endl;
    }
    return 0;
}
```



```
Input
```

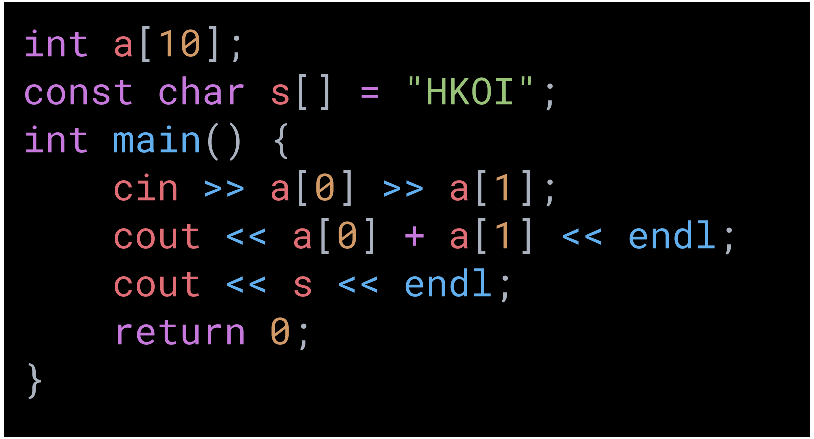


```
Output

1
2
3
4
5
```

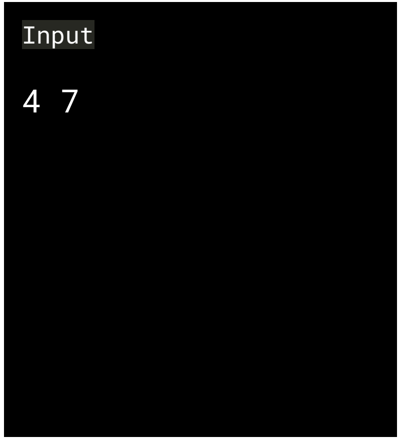
for loop

# Arrays

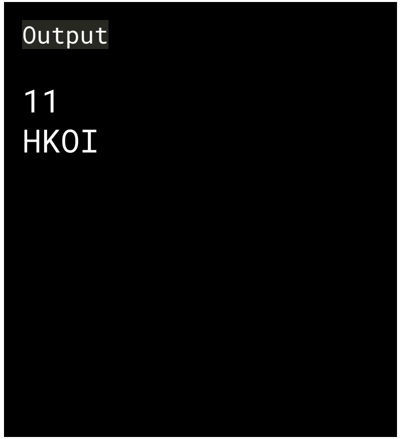
We can use a character array to store strings



```cpp
int a[10];
const char s[] = "HKOI";
int main() {
    cin >> a[0] >> a[1];
    cout << a[0] + a[1] << endl;
    cout << s << endl;
    return 0;
}
```



```
Input

4 7
```

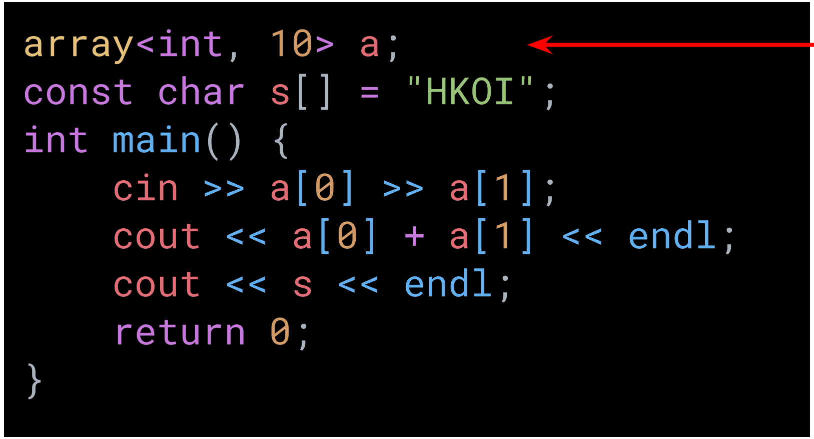


```
Output

11
HKOI
```

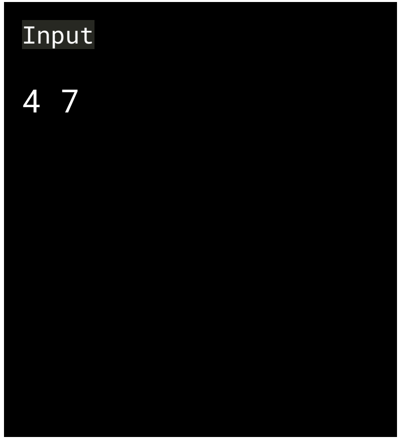
# C++ array

With the exception of const arrays, (e.g. `const char s[]`) modern C++ discourages the use of raw arrays

The type and size of an array is fixed once declared

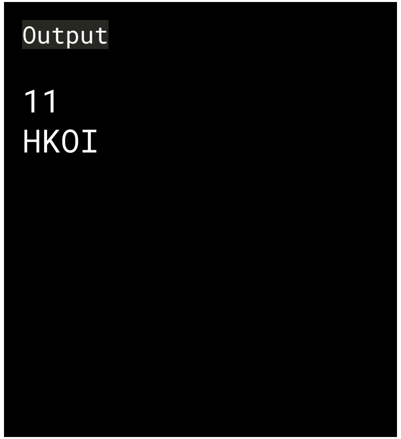


```
array<int, 10> a;
const char s[] = "HKOI";
int main() {
    cin >> a[0] >> a[1];
    cout << a[0] + a[1] << endl;
    cout << s << endl;
    return 0;
}
```



Input

```
4 7
```



Output

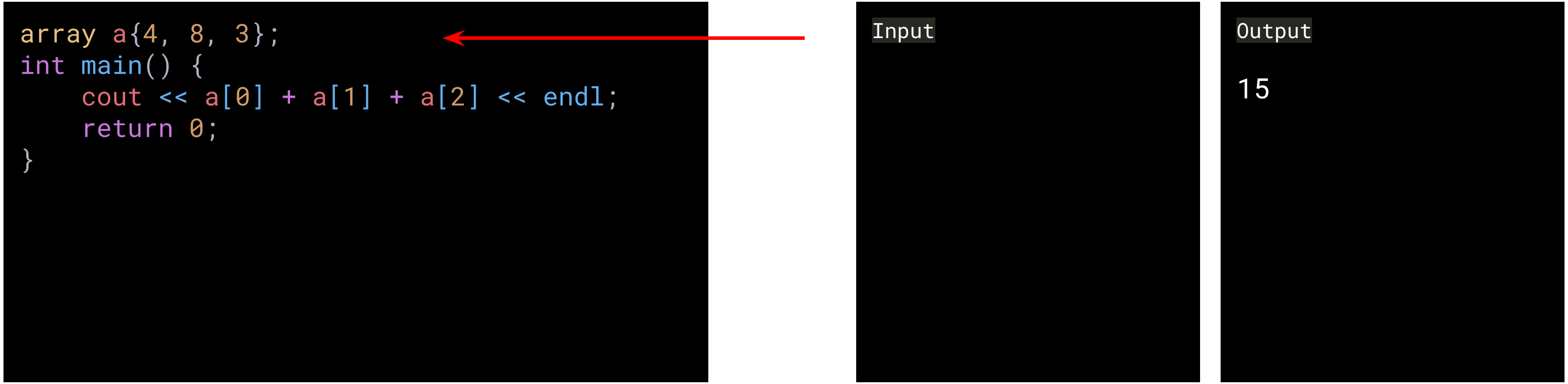
```
11
HKOI
```

array

# C++ array

Arrays can also be declared with initialization

The size and type will be automatically determined (class template argument deduction, since C++17). Here, the type of a is `array<int, 3>`



```
array a{4, 8, 3};
int main() {
    cout << a[0] + a[1] + a[2] << endl;
    return 0;
}
```

```
Input
```

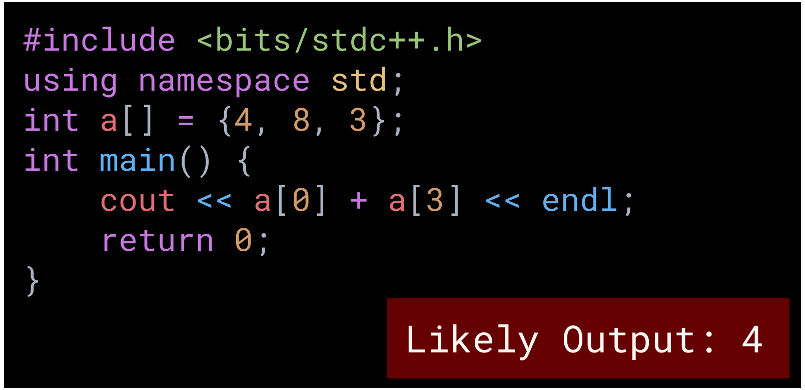
```
Output

15
```

CTAD

# Benefits of C++ array

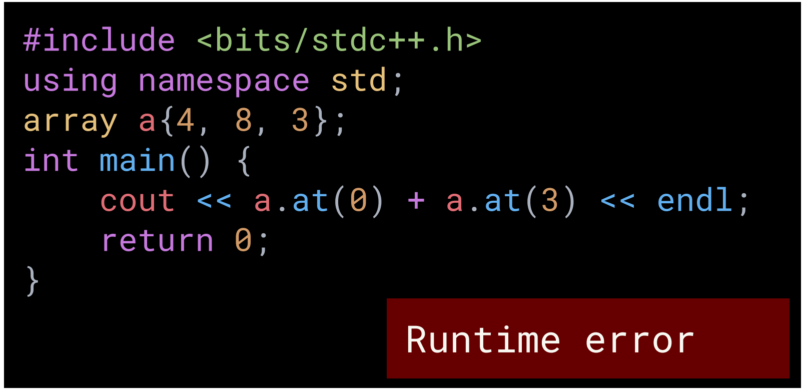
For C array, the identifier degenerates into a pointer when passed into functions

Provides index checking via `.at(index)`, which makes debugging easier



```
#include <bits/stdc++.h>
using namespace std;
int a[] = {4, 8, 3};
int main() {
    cout << a[0] + a[3] << endl;
    return 0;
}
```

Likely Output: 4



```
#include <bits/stdc++.h>
using namespace std;
array a{4, 8, 3};
int main() {
    cout << a.at(0) + a.at(3) << endl;
    return 0;
}
```

Runtime error

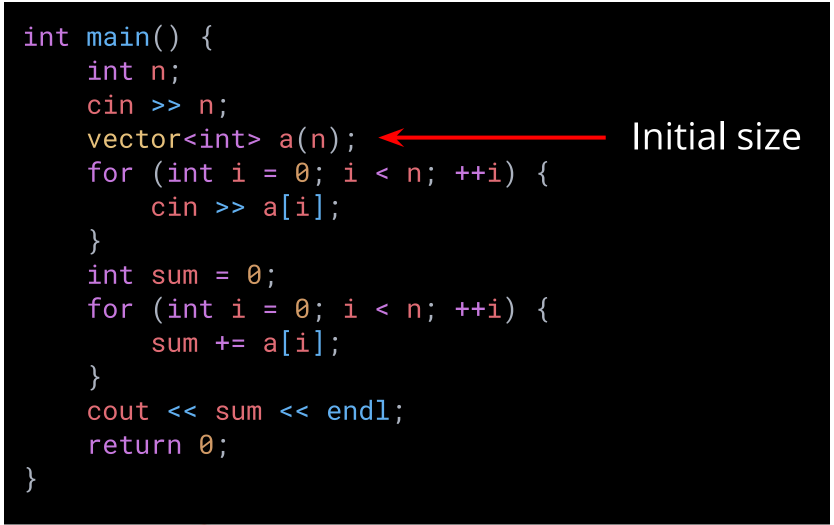
```
terminate called after throwing an instance of 'std::out_of_range'
  what():  array::at: __n (which is 3) >= _Nm (which is 3)
```

at

# Dynamic size array: vector

Very often the task requires us to read N integers

We can use `vector`, which is a dynamic size array to store the data



```cpp
int main() {
    int n;
    cin >> n;
    vector<int> a(n);
    for (int i = 0; i < n; ++i) {
        cin >> a[i];
    }
    int sum = 0;
    for (int i = 0; i < n; ++i) {
        sum += a[i];
    }
    cout << sum << endl;
    return 0;
}
```

Initial size

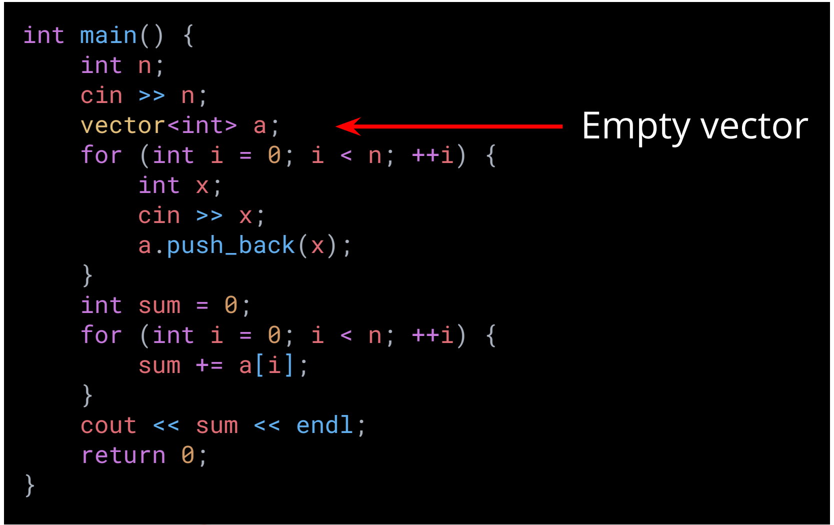
```
Input

6
1 4 2 8 5 7
```

```
Output

27
```

vector

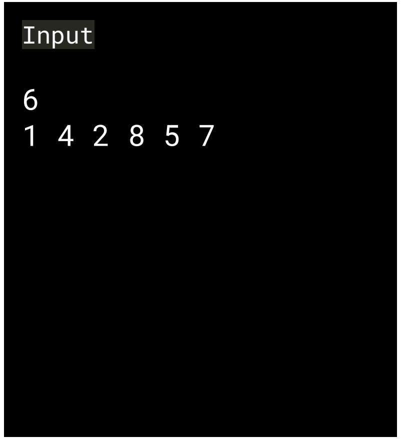
# Dynamic size array: vector

Alternatively, we can start with an empty vector and use `push_back(x)` to add items to the vector while reading

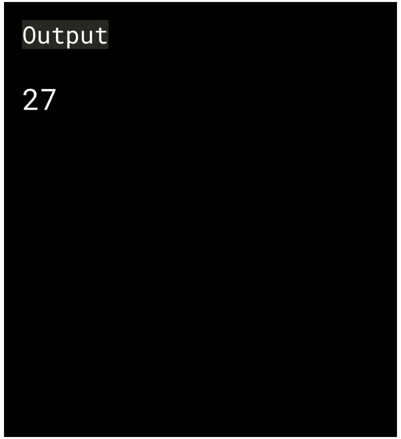


```
int main() {
    int n;
    cin >> n;
    vector<int> a;
    for (int i = 0; i < n; ++i) {
        int x;
        cin >> x;
        a.push_back(x);
    }
    int sum = 0;
    for (int i = 0; i < n; ++i) {
        sum += a[i];
    }
    cout << sum << endl;
    return 0;
}
```

Empty vector



```
Input

6
1 4 2 8 5 7
```

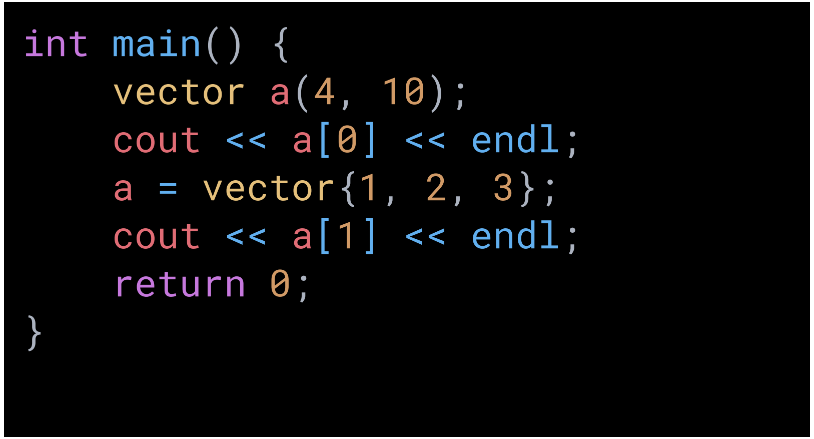


```
Output

27
```

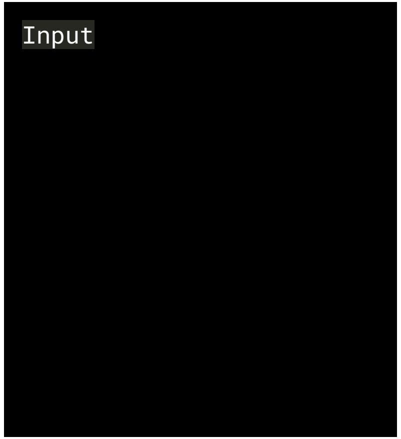
push_back

# vector assignment

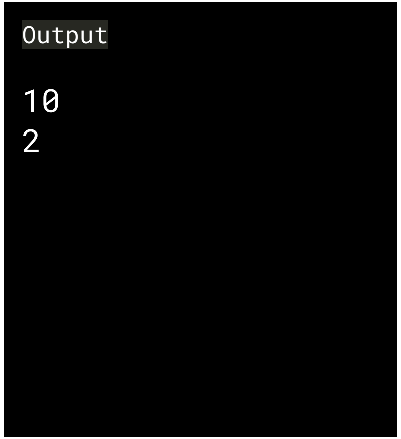
We can replace the entire vector by assigning another vector to it



```
int main() {
    vector a(4, 10);
    cout << a[0] << endl;
    a = vector{1, 2, 3};
    cout << a[1] << endl;
    return 0;
}
```



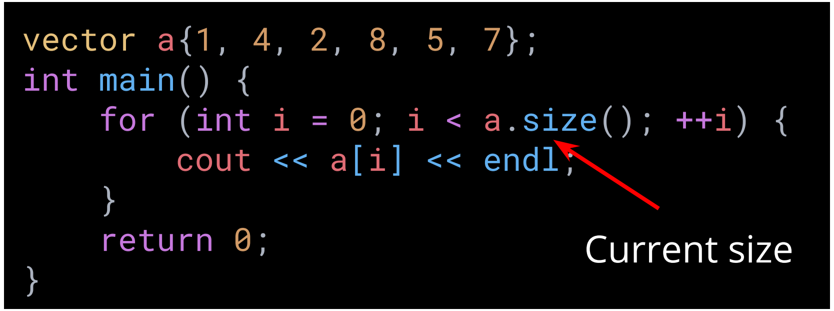
```
Input
```



```
Output

10
2
```

operator=

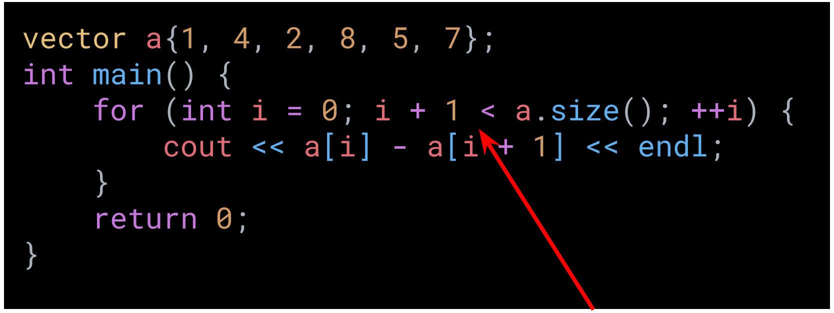
# Iterate over vector - int i



```
vector a{1, 4, 2, 8, 5, 7};
int main() {
    for (int i = 0; i < a.size(); ++i) {
        cout << a[i] << endl;
    }
    return 0;
}
```

Current size

```
Output

1
4
2
8
5
7
```



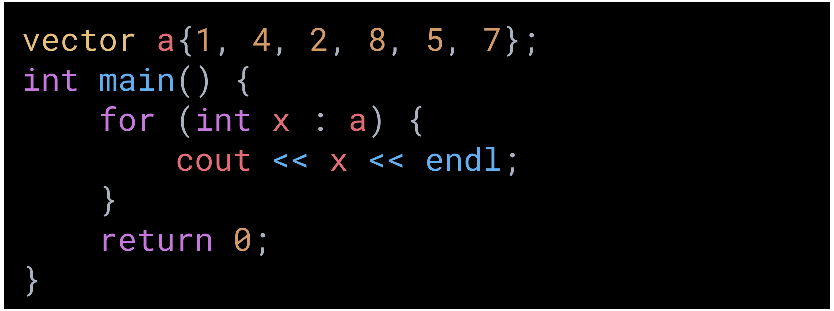
```
vector a{1, 4, 2, 8, 5, 7};
int main() {
    for (int i = 0; i + 1 < a.size(); ++i) {
        cout << a[i] - a[i + 1] << endl;
    }
    return 0;
}
```

```
Output

-3
2
-6
3
-2
```

Is it ok to write **`i < a.size() - 1`**?

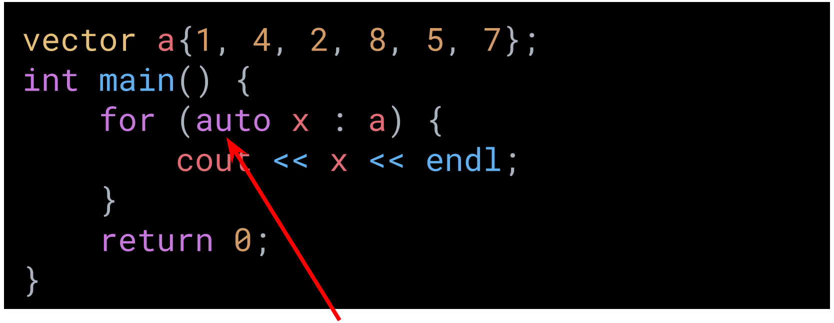
size

# Iterate over vector - range-based for loop



```
vector a{1, 4, 2, 8, 5, 7};
int main() {
    for (int x : a) {
        cout << x << endl;
    }
    return 0;
}
```

```
Output

1
4
2
8
5
7
```



```
vector a{1, 4, 2, 8, 5, 7};
int main() {
    for (auto x : a) {
        cout << x << endl;
    }
    return 0;
}
```

```
Output

1
4
2
8
5
7
```

You can use **auto** when type can be automatically determined

[Range-based for loop]

# Modifying values in range-based loop

```
vector a{1, 4, 2, 8, 5, 7};
int main() {
    for (int x : a) {
        x = 3;
    }
    cout << a[0] << endl;
    return 0;
}
```

Value of a[0], a[1], ... is copied to x

```
Output

1
```

```
vector a{1, 4, 2, 8, 5, 7};
int main() {
    for (int& x : a) {
        x = 3;
    }
    cout << a[0] << endl;
    return 0;
}
```

Reference: x is same as a[0], a[1]...

```
Output

3
```

Reference declaration

# Iterate over vector - iterator

```
vector a{1, 4, 2, 8, 5, 7};
int main() {
    for (auto it = a.begin(); it != a.end(); ++it) {
        cout << *it << endl;
    }
    return 0;
}
```

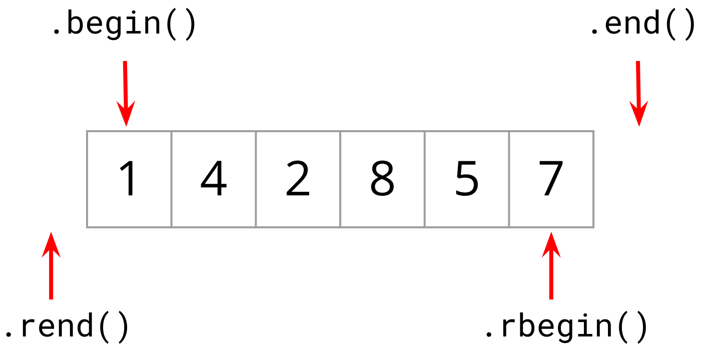
De-reference (get data being pointed at)

```
Output

1
4
2
8
5
7
```

```
vector a{1, 4, 2, 8, 5, 7};
int main() {
    for (auto it = a.rbegin(); it != a.rend(); ++it) {
        cout << *it << endl;
    }
    return 0;
}
```

```
Output

7
5
8
2
4
1
```

Type: `vector<int>::iterator`



Type: `vector<int>::reverse_iterator`

begin end rbegin rend
RandomAccessIterator

# Modifying values using iterator

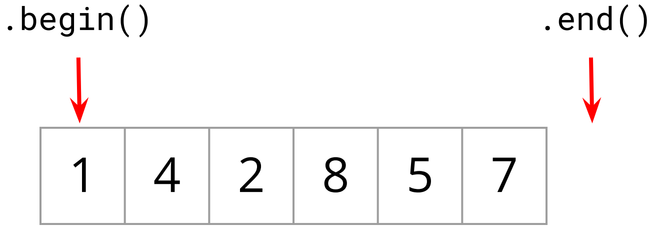
```
vector a{1, 4, 2, 8, 5, 7};
int main() {
    auto it = a.begin();
    *it = 3;
    cout << a[0] << endl;
    return 0;
}
```

```
Output
3
```

```
vector a{1, 4, 2, 8, 5, 7};
int main() {
    auto it = a.end();
    *it = 3;
    cout << a[0] << endl;
    return 0;
}
```

```
Output
1
```

Possibly runtime error



# Sort a vector

Use `sort(first, last)` to sort a vector in ascending order

Use `reverse(first, last)` to reverse a vector

```
vector a{1, 4, 2, 8, 5, 7};
int main() {
    sort(a.begin(), a.end());
    for (int x : a) {
        cout << x << " ";
    }
    cout << endl;
    reverse(a.begin(), a.end());
    for (int x : a) {
        cout << x << " ";
    }
    cout << endl;
    return 0;
}
```

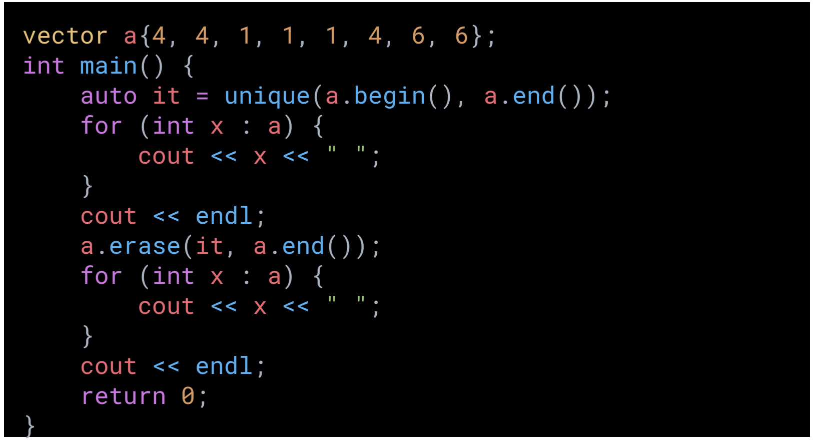
```
Output

1 2 4 5 7 8
8 7 5 4 2 1
```

sort reverse

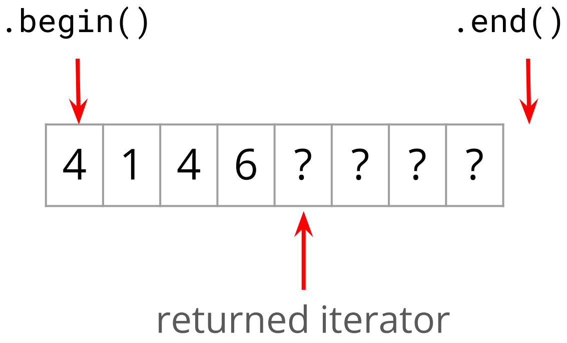
# Removing duplicates from a vector

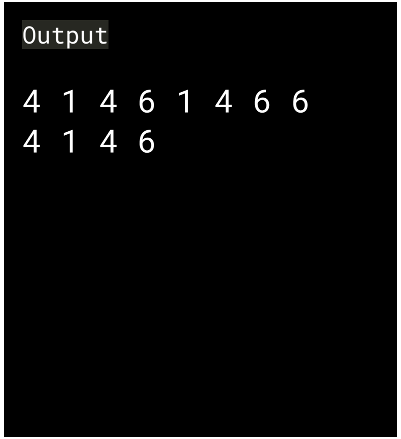
Use `unique(first, last)` to move the first element in each identical group to the front, keeping their relative order. The returned iterator points to the position after the last remaining element.

Use `erase(first, last)` to remove elements from a vector



```
vector a{4, 4, 1, 1, 1, 4, 6, 6};
int main() {
    auto it = unique(a.begin(), a.end());
    for (int x : a) {
        cout << x << " ";
    }
    cout << endl;
    a.erase(it, a.end());
    for (int x : a) {
        cout << x << " ";
    }
    cout << endl;
    return 0;
}
```





```
Output

4 1 4 6 1 4 6 6
4 1 4 6
```

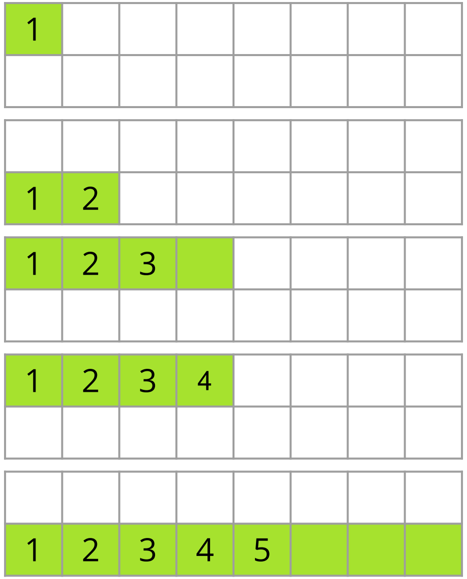
unique erase

# Internal storage

Vector always store the data in contiguous segment of memory

When it is already full and you try to push one more element, it finds a larger piece of memory elsewhere and move all the data there

```
int main() {
    vector<int> a;
    cout << a.capacity() << " ";
    cout << a.data() << endl;
    for (int i = 1; i <= 6; ++i) {
        a.push_back(i);
        cout << a.capacity() << " ";
        cout << a.data() << endl;
    }
    return 0;
}
```



```
Output

0 0
1 0x55d4f682d2c0
2 0x55d4f682d2e0
4 0x55d4f682d2c0
4 0x55d4f682d2c0
8 0x55d4f682d300
8 0x55d4f682d300
```

capacity data

# Time complexity for push_back

Assume that you call `push_back(x)` N times.

The total cost comprises of:

- Cost of adding an element
  - 1 operation per push_back
  - Total N operations for N push_back
- Cost of moving elements when vector is full
  - 1, 2, 4, 8, ..., $2^k$ (where $2^k < N$)
  - The sum of above = $2^{k+1} - 1 < 2N$

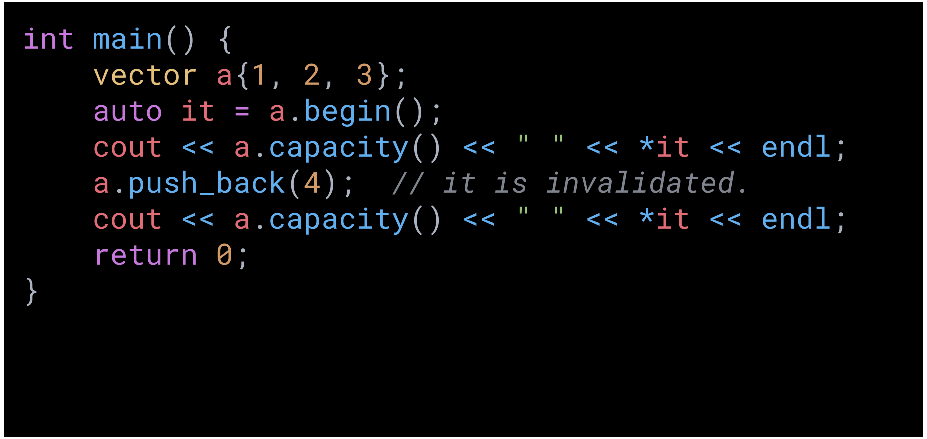
Total cost for N push_back = N + (<2N) < 3N, and therefore is O(N)
We can say that push_back is amortized O(1)

push_back

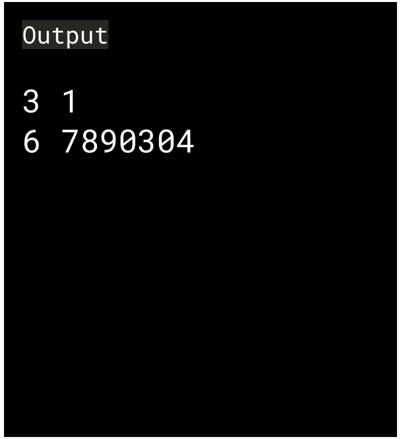
# Be careful about iterators

Some manipulation operations, especially when they affect the internal storage, **invalidate** iterators. Read the docs for details

If unsure, always get fresh iterators



```
int main() {
    vector a{1, 2, 3};
    auto it = a.begin();
    cout << a.capacity() << " " << *it << endl;
    a.push_back(4);  // it is invalidated.
    cout << a.capacity() << " " << *it << endl;
    return 0;
}
```



Output

```
3 1
6 7890304
```

push_back

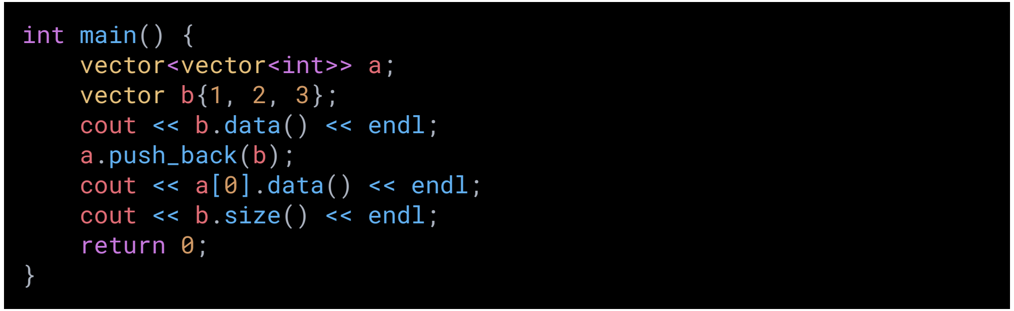
# 2D vector

```
vector<vector<int>> a{{1, 2, 3}, {4}, {5, 6}};
int main() {
    cout << a[0].size() << endl;
    cout << a[1].size() << endl;
    cout << a[2].size() << endl;
    cout << a[2][0] << endl;
    return 0;
}
```

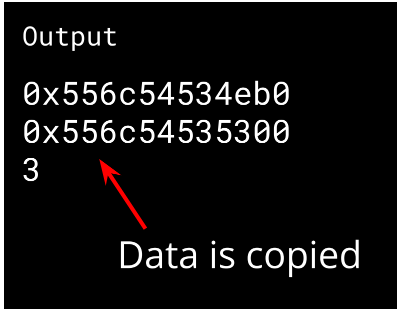
```
Output

3
1
2
5
```

```
int main() {
    int n = 4, m = 5;
    vector a(n, vector<int>(m));
    for (int i = 0; i < n; ++i) {
        for (int j = 0; j < m; ++j) {
            cin >> a[i][j];
        }
    }
    return 0;
}
```

# Remember move()?

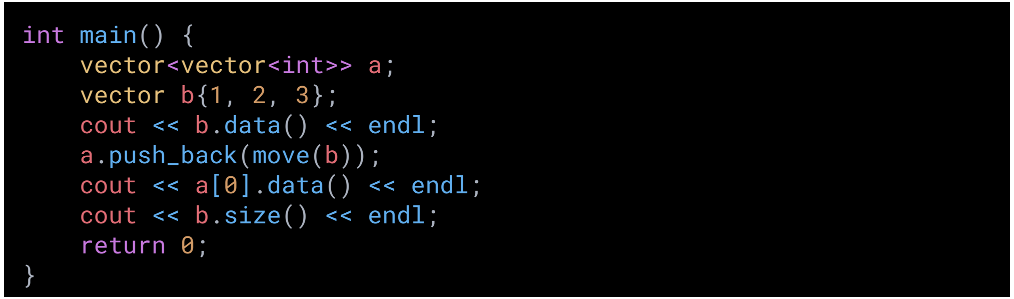


```
int main() {
    vector<vector<int>> a;
    vector b{1, 2, 3};
    cout << b.data() << endl;
    a.push_back(b);
    cout << a[0].data() << endl;
    cout << b.size() << endl;
    return 0;
}
```

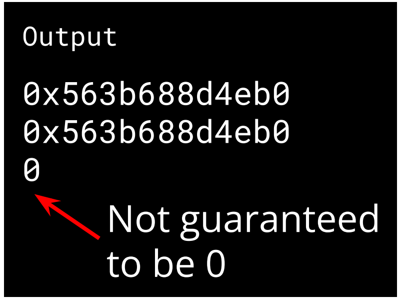


```
Output

0x556c54534eb0
0x556c54535300
3
```

Data is copied



```
int main() {
    vector<vector<int>> a;
    vector b{1, 2, 3};
    cout << b.data() << endl;
    a.push_back(move(b));
    cout << a[0].data() << endl;
    cout << b.size() << endl;
    return 0;
}
```



```
Output

0x563b688d4eb0
0x563b688d4eb0
0
```

Not guaranteed to be 0

`std::move()` is complicated

No need to care about it in competitive programming

data move

# vector<bool>

`vector<bool>` is a very special kind of vector

Its implementation allows efficient storage of bools, 1 bit (vs 1 byte) for each bool

Some vector functions cannot be used

```cpp
vector<bool> a{true, false, true};
int main() {
    cout << a[0] << a[1] << a[2] << endl;
    cout << a.capacity() << endl;
    a.flip();
    cout << a[0] << a[1] << a[2] << endl;
    return 0;
}
```

```
Output

101
64
010
```

vector<bool>

# Strings

C++ strings are very easy to use

You can concatenate strings together using the + operator

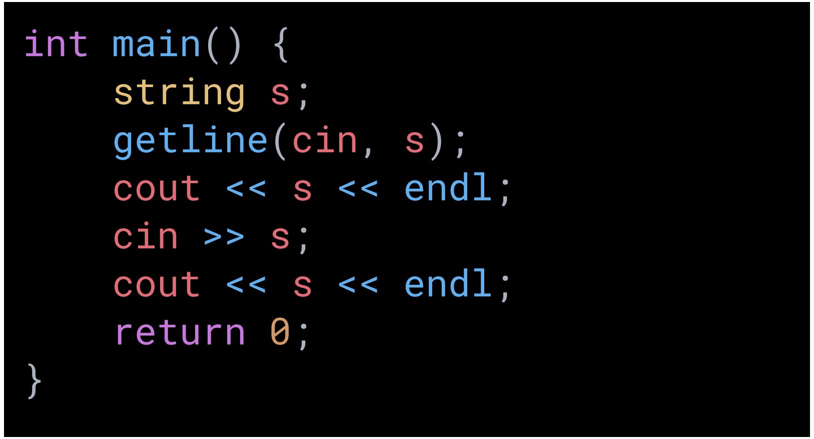
```cpp
int main() {
    string s = "ab";
    string t = "d";
    s += 'c';  // append a character
    t += "ef";  // append a string
    cout << s.length() << endl;
    cout << s + t << endl;
    return 0;
}
```

```
Output

3
abcdef
```

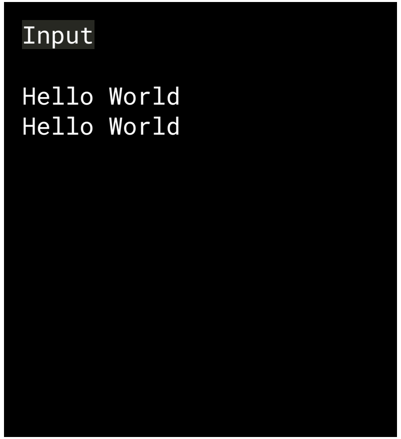
length operator+ operator+=

# Read one line

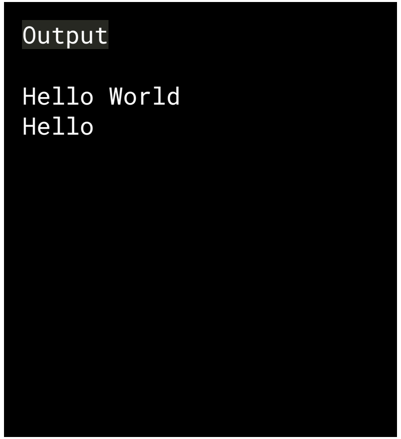
Use getline to read one line



```
int main() {
    string s;
    getline(cin, s);
    cout << s << endl;
    cin >> s;
    cout << s << endl;
    return 0;
}
```



```
Input

Hello World
Hello World
```



```
Output

Hello World
Hello
```

getline

# Iterate over string

You can also use ranged-based loop to iterate over a string

```
int main() {
    string s = "abcdef";
    for (int i = 0; i < s.length(); ++i) {
        cout << s[i] << endl;
    }
    for (char& c : s) {
        c -= 32;
    }
    cout << s << endl;
    return 0;
}
```

```
Output

a
b
c
d
e
f
ABCDEF
```

# Using string::iterator

You can get iterators from string to perform operations similar to vector

```
int main() {
    string s = "abcdef";
    for (auto it = s.begin(); it != s.end(); ++it) {
        cout << *it << endl;
    }
    reverse(s.begin(), s.end());
    cout << s << endl;
    return 0;
}
```

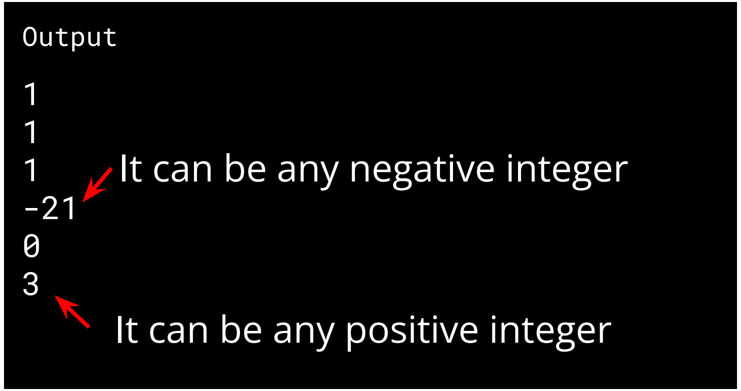
```
Output

a
b
c
d
e
f
fedcba
```

# String comparison

You can compare strings directly using comparison operators

You can also use `.compare()`, which returns 0 when the strings are equal, negative number when the left string is smaller, and positive otherwise

```cpp
int main() {
    cout << ("abc"s == "abc"s) << endl;
    cout << ("abc"s < "def"s) << endl;
    cout << ("abcd"s > "abc"s) << endl;
    cout << "abc"s.compare("abx") << endl;
    cout << "xyz"s.compare("xyz") << endl;
    cout << "def"s.compare("a") << endl;
    return 0;
}
```



```
Output

1
1
1
-21
0
3
```

It can be any negative integer

It can be any positive integer

compare

# Find string

Syntax: `s.find(char / string, (optional)pos)`

Returns `string::npos if not found`

```
int main() {
    int n;
    string s = "This is a string";
    n = s.find("is");
    cout << n << endl;
    n = s.find("is", 5);
    cout << n << endl;
    n = s.find('q');
    cout << n << endl;
    cout << string::npos << endl;
    return 0;
}
```

```
Input
```

```
Output

2
5
-1
18446744073709551615
```

find

# Modify string

```
s.insert(pos, string, (optional)count)
s.erase(pos, (optional)count)
s.replace(pos, count, string, (optional)count2)
```

```
int main() {
    string s = "abc";
    s.insert(1, "abc", 2);
    cout << s << endl;
    s.erase(3);
    cout << s << endl;
    s.replace(1, 1, "123");
    cout << s << endl;
    return 0;
}
```

```
Input
```

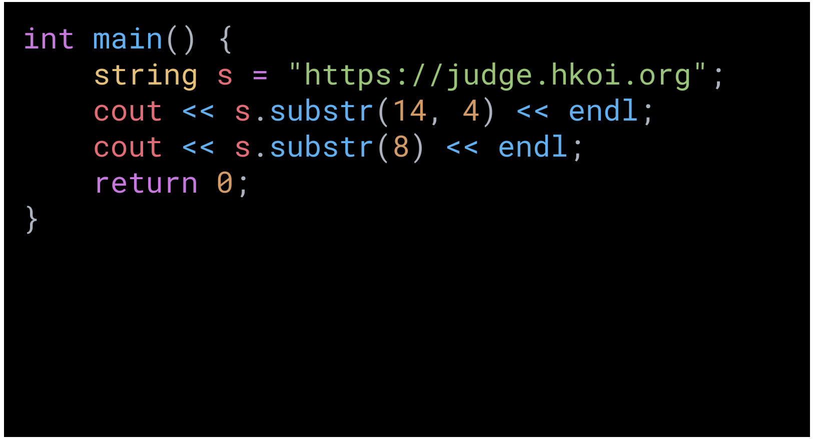
```
Output

aabbc
aab
a123b
```

insert erase replace

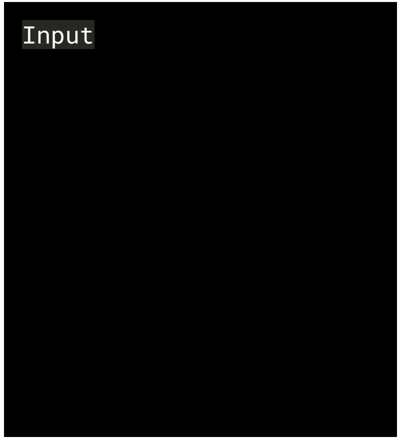
# Get substring

syntax: `s.substr(pos, (optional)count)`

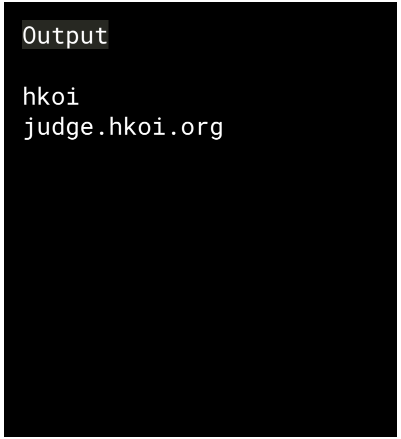
Returns the substring



```
int main() {
    string s = "https://judge.hkoi.org";
    cout << s.substr(14, 4) << endl;
    cout << s.substr(8) << endl;
    return 0;
}
```



```
Input
```



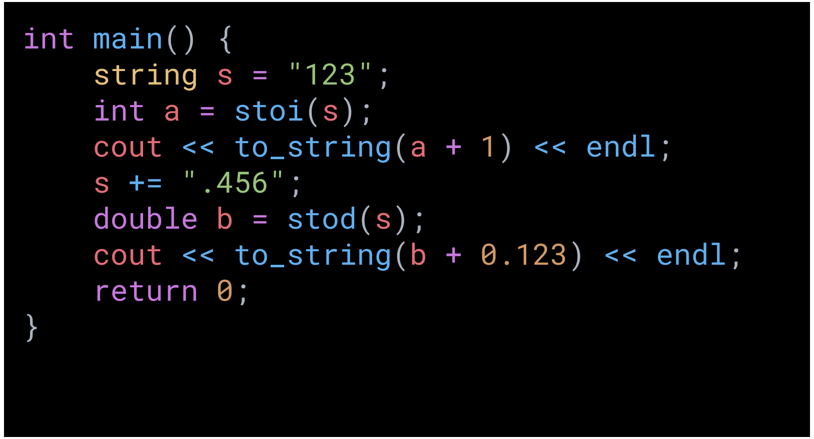
```
Output

hkoi
judge.hkoi.org
```

substr

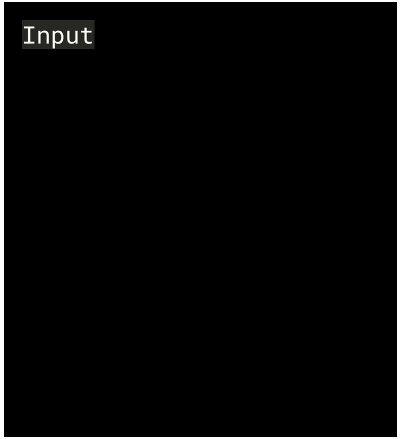
# String conversion (since C++11)

Use `stoi`, `stod`, etc. to convert the string to a number type

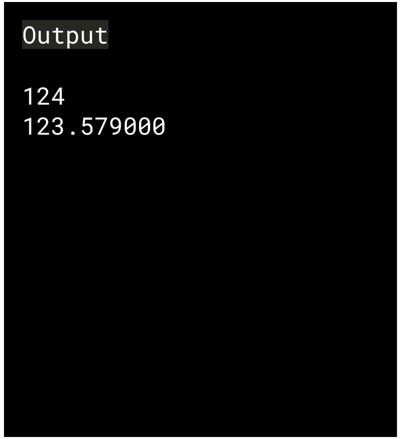
Use `to_string` to convert a number type to string



```
int main() {
    string s = "123";
    int a = stoi(s);
    cout << to_string(a + 1) << endl;
    s += ".456";
    double b = stod(s);
    cout << to_string(b + 0.123) << endl;
    return 0;
}
```



```
Input
```



```
Output

124
123.579000
```

stoi stod to_string

# Break

Please read J021 and M2102 problem statement

Training session will resume at 11:50

# Functions

Functions with return type should have a return statement.

Void functions can omit the return statement.

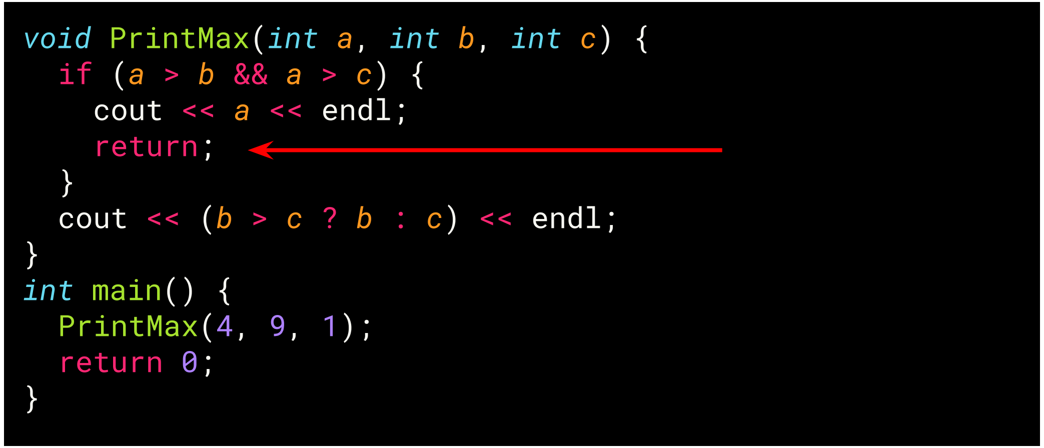
```
int Square(int x) {
  return x * x;
}
void PrintMax(int a, int b, int c) {
  cout << max(a, max(b, c)) << endl;
}
int main() {
  cout << Square(5) << endl;
  PrintMax(4, 9, 1);
  return 0;
}
```

```
Output

25
9
```

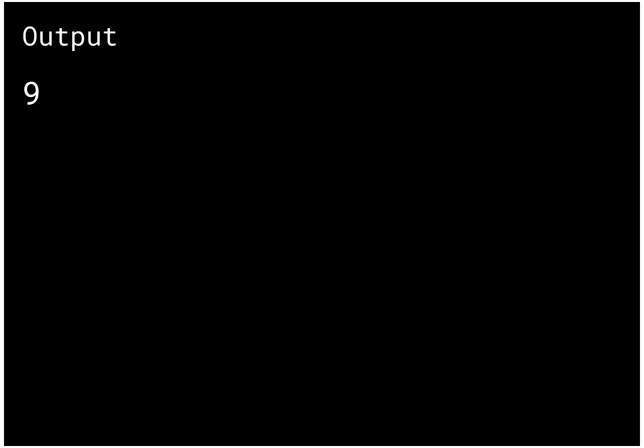
Function declaration

# Early Return

If you have a return statement at the end of a if block, no need to add else.



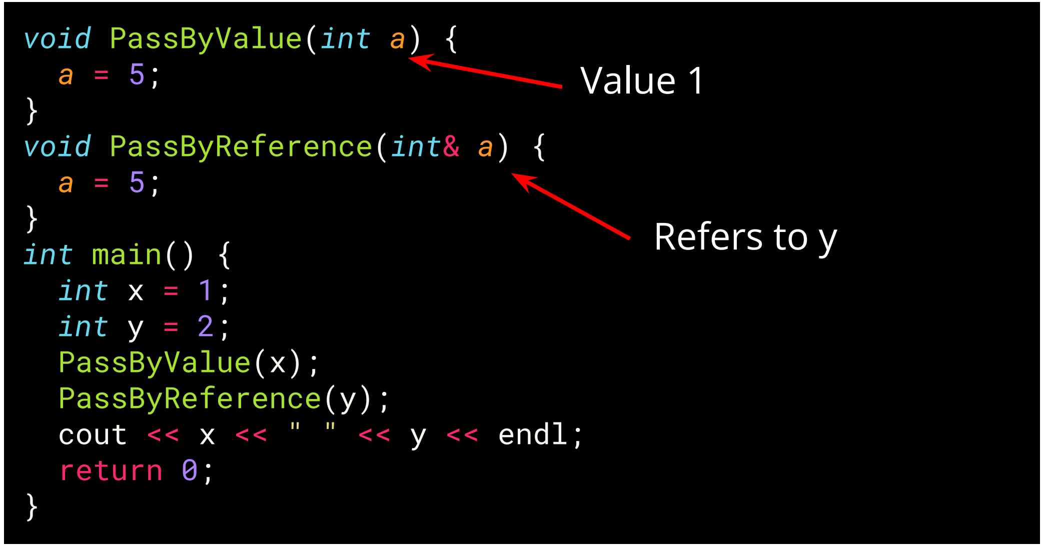
```
void PrintMax(int a, int b, int c) {
  if (a > b && a > c) {
    cout << a << endl;
    return;
  }
  cout << (b > c ? b : c) << endl;
}
int main() {
  PrintMax(4, 9, 1);
  return 0;
}
```



```
Output

9
```

# Pass by reference

Pass by reference makes the identifier refer to the same variable specified in the argument. Therefore, the value can be changed inside the function.



```cpp
void PassByValue(int a) {
  a = 5;
}
void PassByReference(int& a) {
  a = 5;
}
int main() {
  int x = 1;
  int y = 2;
  PassByValue(x);
  PassByReference(y);
  cout << x << " " << y << endl;
  return 0;
}
```

Value 1

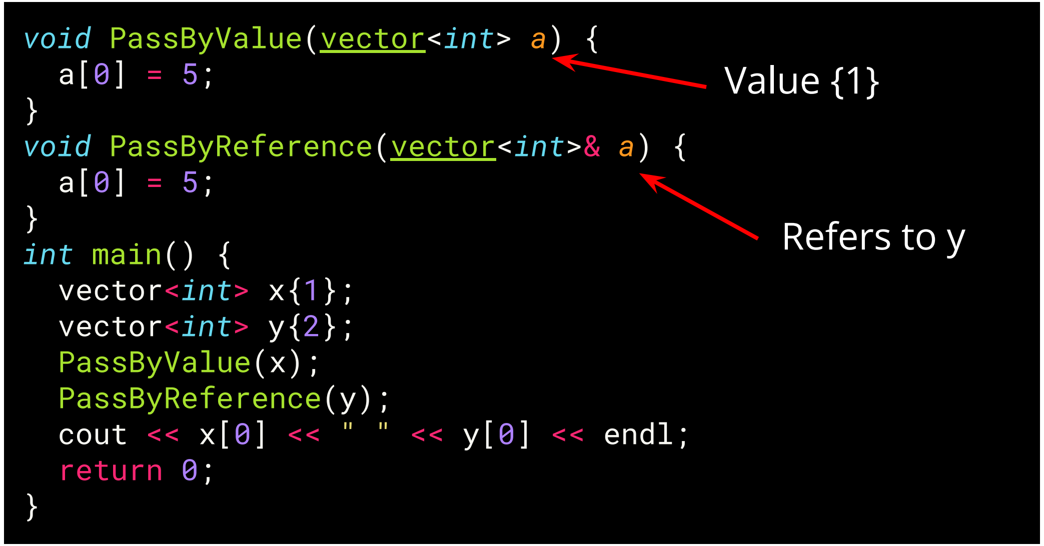
Refers to y

```
Output

1 5
```

Reference declaration

# Pass by reference: vector

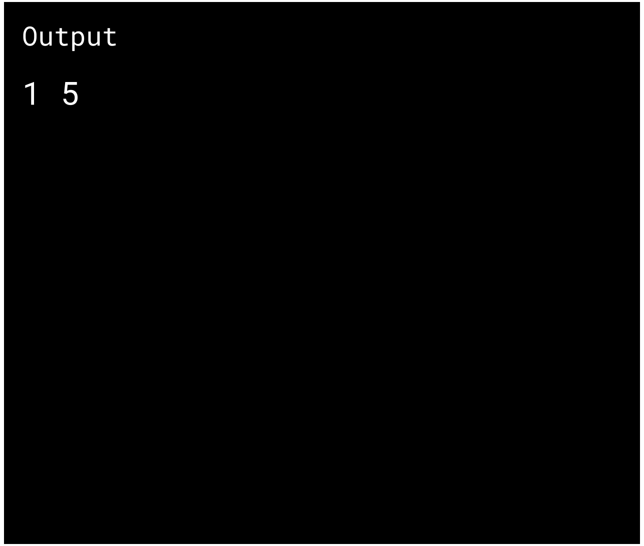
All types are passed by value. (unlike Java / Javascript)



```
void PassByValue(vector<int> a) {
  a[0] = 5;
}
void PassByReference(vector<int>& a) {
  a[0] = 5;
}
int main() {
  vector<int> x{1};
  vector<int> y{2};
  PassByValue(x);
  PassByReference(y);
  cout << x[0] << " " << y[0] << endl;
  return 0;
}
```

Value {1}

Refers to y



```
Output

1 5
```

# Pass by value is slow

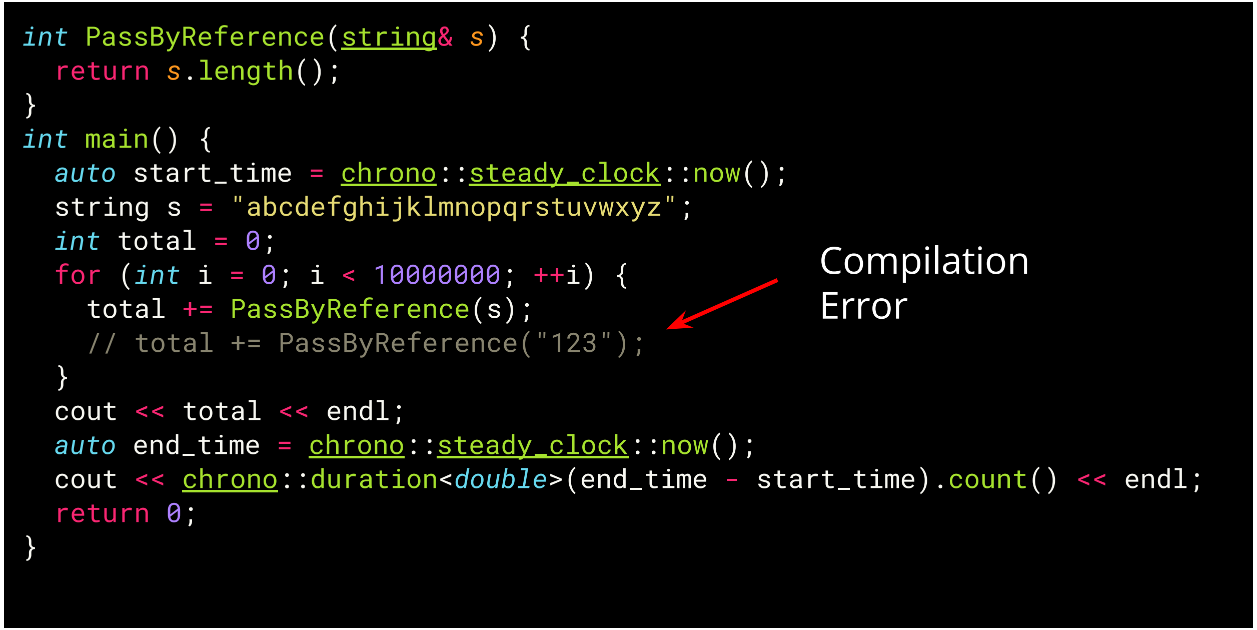
```cpp
int PassByValue(string s) {
  return s.length();
}
int PassByReference(string& s) {
  return s.length();
}
int main() {
  auto start_time = chrono::steady_clock::now();
  string s = "abcdefghijklmnopqrstuvwxyz";
  int total = 0;
  for (int i = 0; i < 10000000; ++i) {
    total += PassByValue(s);
  }
  cout << total << endl;
  auto end_time = chrono::steady_clock::now();
  cout << chrono::duration<double>(end_time - start_time).count() << endl;
  start_time = end_time;
  total = 0;
  for (int i = 0; i < 10000000; ++i) {
    total += PassByReference(s);
  }
  cout << total << endl;
  end_time = chrono::steady_clock::now();
  cout << chrono::duration<double>(end_time - start_time).count() << endl;
  return 0;
}
```

```
Output

260000000
2.6825
260000000
0.0452582
```

PassByValue:
A new string a is created and the content is copied from s

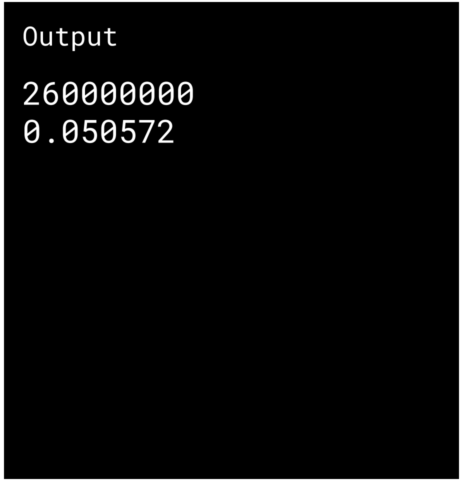
now duration

# Cannot pass something other than variable by reference



```cpp
int PassByReference(string& s) {
  return s.length();
}
int main() {
  auto start_time = chrono::steady_clock::now();
  string s = "abcdefghijklmnopqrstuvwxyz";
  int total = 0;
  for (int i = 0; i < 10000000; ++i) {
    total += PassByReference(s);
    // total += PassByReference("123");
  }
  cout << total << endl;
  auto end_time = chrono::steady_clock::now();
  cout << chrono::duration<double>(end_time - start_time).count() << endl;
  return 0;
}
```

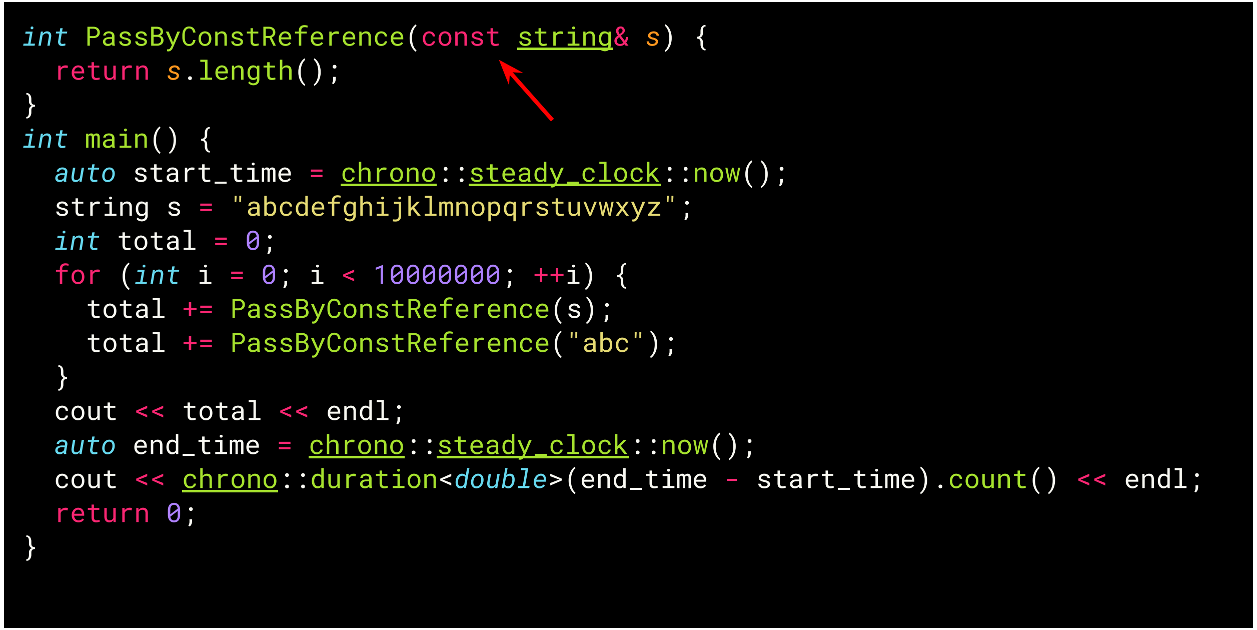
Compilation Error



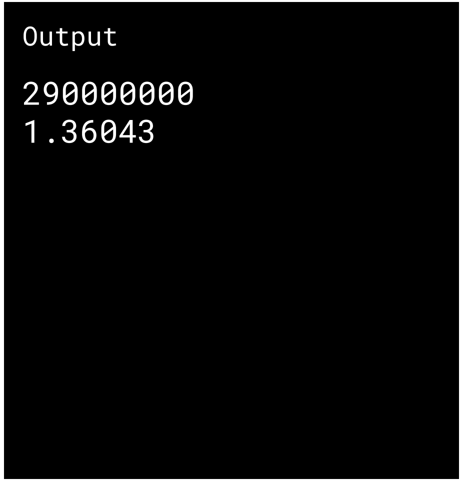
```
Output

260000000
0.050572
```

Technical term:
To pass by reference, the argument must be an lvalue.

# Pass by Const Reference



```
int PassByConstReference(const string& s) {
  return s.length();
}
int main() {
  auto start_time = chrono::steady_clock::now();
  string s = "abcdefghijklmnopqrstuvwxyz";
  int total = 0;
  for (int i = 0; i < 10000000; ++i) {
    total += PassByConstReference(s);
    total += PassByConstReference("abc");
  }
  cout << total << endl;
  auto end_time = chrono::steady_clock::now();
  cout << chrono::duration<double>(end_time - start_time).count() << endl;
  return 0;
}
```



```
Output

290000000
1.36043
```

Don't do this for primitives such as int, double, bool

# Template

```cpp
template<class T>
ostream& operator<<(ostream& os,
                    const vector<T>& c) {
  for (auto&& x : c) {
    cout << x << " ";
  }
  cout << endl;
  return os;
}
int main() {
  vector<int> a{1, 2, 3, 4, 5};
  cout << a;
  vector<double> b{1.2, 3.4, 5.6};
  cout << b;
  return 0;
}
```

```
Output

1 2 3 4 5
1.2 3.4 5.6
```

Templates

# Output a 2D vector

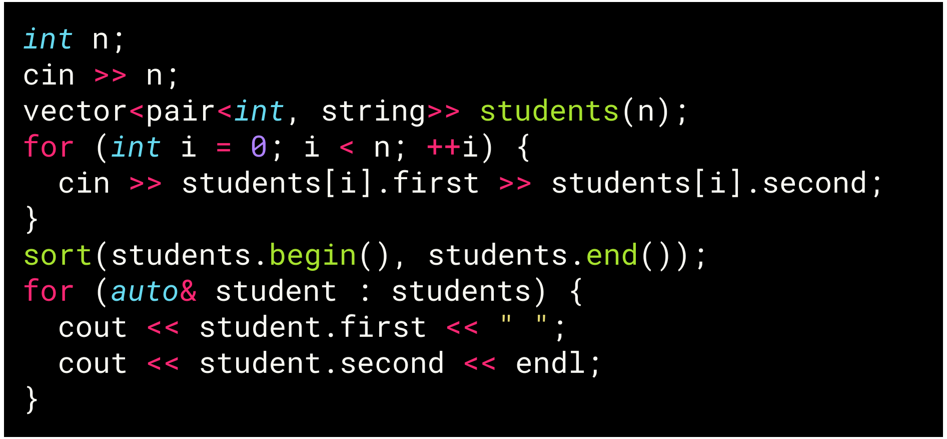
```
template<class T>
ostream& operator<<(ostream& os,
                    const vector<T>& c) {
  for (auto&& x : c) {
    cout << x << " ";
  }
  cout << endl;
  return os;
}
int main() {
  vector<vector<int>> a{{11, 12, 13},
                        {21, 22},
                        {31, 32, 33}};

  cout << a;
  return 0;
}
```

```
Output

11 12 13
 21 22
 31 32 33
```

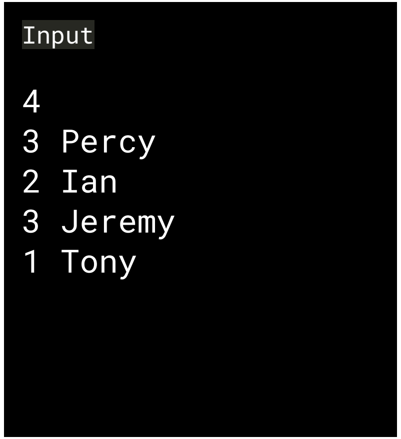
# Pair

Pair can hold two values (`first`, `second`) of possibly different types.

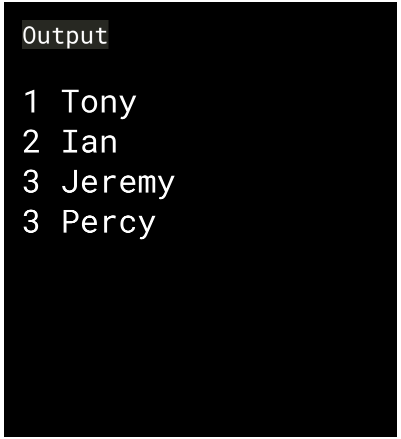
Pairs can be compared. The first value will be compared first. If they are equal, the second value will be compared.



```cpp
int n;
cin >> n;
vector<pair<int, string>> students(n);
for (int i = 0; i < n; ++i) {
  cin >> students[i].first >> students[i].second;
}
sort(students.begin(), students.end());
for (auto& student : students) {
  cout << student.first << " ";
  cout << student.second << endl;
}
```



```
Input

4
3 Percy
2 Ian
3 Jeremy
1 Tony
```



```
Output

1 Tony
2 Ian
3 Jeremy
3 Percy
```

pair

# Pair

Pair can be useful to return multiple values.

```cpp
pair<int, int> CountLetters(const string& s) {
  int upper = 0, lower = 0;
  for (char c : s) {
    upper += isupper(c) > 0;
    lower += islower(c) > 0;
  }
  return {upper, lower};
}
int main() {
  auto p = CountLetters("Hello, World!");
  cout << p.first << " " << p.second << endl;
  return 0;
}
```

```
Output

2 8
```

isupper islower

# Tuple

What about more values?

```cpp
tuple<int, int, int> CountLetters(const string& s) {
  int upper = 0, lower = 0, spaces = 0;
  for (char c : s) {
    upper += isupper(c) > 0;
    lower += islower(c) > 0;
    spaces += c == ' ';
  }
  return {upper, lower, spaces};
}
int main() {
  auto p = CountLetters("Hello, World!");
  cout << get<0>(p) << " " << get<1>(p) << " ";
  cout << get<2>(p) << endl;
  return 0;
}
```

```
Output

2 8 1
```

get(tuple)

# J021 Date sorting

Given N dates, sort the dates in chronological order.

```
Input

3
4, July 1981
18, October 1982
22, December 1981
```

```
Output

4, July 1981
22, December 1981
18, October 1982
```

# Reading the input

Let’s read one line of input.

cin.get() reads the next character, which is comma here.

```
int day, year;
string month_string;
cin >> day;
cin.get();
cin >> month_string >> year;
cout << day << endl;
cout << month_string << endl;
cout << year << endl;
```

Input

```
20, February 2021
```

Output

```
20
February
2021
```

get

# Converting the month into an integer

```
const vector<string> kMonths =
    {"January", "February", "March", "April", "May", "June",
     "July", "August", "September", "October", "November", "December"};
int main() {
  int day, month, year;
  string month_string;
  cin >> day;
  cin.get();
  cin >> month_string >> year;
  auto it = find(kMonths.begin(), kMonths.end(), month_string);
  month = distance(kMonths.begin(), it);
  cout << day << endl;
  cout << month << endl;
  cout << year << endl;
  return 0;
}
```

Input

```
20, February 2021
```

Output

```
20
1
2021
```

find distance

# Storing the dates in a vector<tuple<int, int, int>>

```
const vector<string> kMonths =
    {"January", "February", "March", "April", "May", "June",
     "July", "August", "September", "October", "November", "December"};
int main() {
  int n;
  cin >> n;
  vector<tuple<int, int, int>> dates;
  for (int i = 0; i < n; ++i) {
    int day, month, year;
    string month_string;
    cin >> day;
    cin.get();
    cin >> month_string >> year;
    auto it = find(kMonths.begin(), kMonths.end(), month_string);
    month = distance(kMonths.begin(), it);
    dates.push_back({year, month, day});
    // dates.emplace_back(year, month, day);
  }
  cout << get<1>(dates[2]) << endl;
  return 0;
}
```

The most significant component should go first

You can also use emplace_back

```
Input

3
4, July 1981
18, October 1982
22, December 1981
```

```
Output

11
```

emplace_back

# Alternative way

```
const vector<string> kMonths =
    {"January", "February", "March", "April", "May", "June",
     "July", "August", "September", "October", "November", "December"};
int main() {
  int n;
  cin >> n;
  vector<tuple<int, int, int>> dates(n);
  for (auto& date : dates) {
    cin >> get<2>(date);
    cin.get();
    string month_string;
    cin >> month_string >> get<0>(date);
    auto it = find(kMonths.begin(), kMonths.end(), month_string);
    get<1>(date) = distance(kMonths.begin(), it);
  }
  cout << get<1>(dates[2]) << endl;
  return 0;
}
```

Input

```
3
4, July 1981
18, October 1982
22, December 1981
```

Output

```
11
```

# Even fancier

```cpp
const vector<string> kMonths =
    {"January", "February", "March", "April", "May", "June",
     "July", "August", "September", "October", "November", "December"};
int main() {
  int n;
  cin >> n;
  vector<tuple<int, int, int>> dates(n);
  for (auto& [year, month, day] : dates) {
    cin >> day;
    cin.get();
    string month_string;
    cin >> month_string >> year;
    auto it = find(kMonths.begin(), kMonths.end(), month_string);
    month = distance(kMonths.begin(), it);
  }
  cout << get<1>(dates[2]) << endl;
  return 0;
}
```

Structured binding declaration (since C++17), must be auto

```
Input

3
4, July 1981
18, October 1982
22, December 1981
```

```
Output

11
```

# Output the sorted dates

```
 vector<tuple<int, int, int>> dates(n);
 ... input ...
 sort(dates.begin(), dates.end());
 for (auto& date : dates) {
  cout << get<2>(date) << ", ";
  cout << kMonths[get<1>(date)] << " ";
  cout << get<0>(date) << endl;
 }
 return 0;
}
```

```
Input

3
4, July 1981
18, October 1982
22, December 1981
```

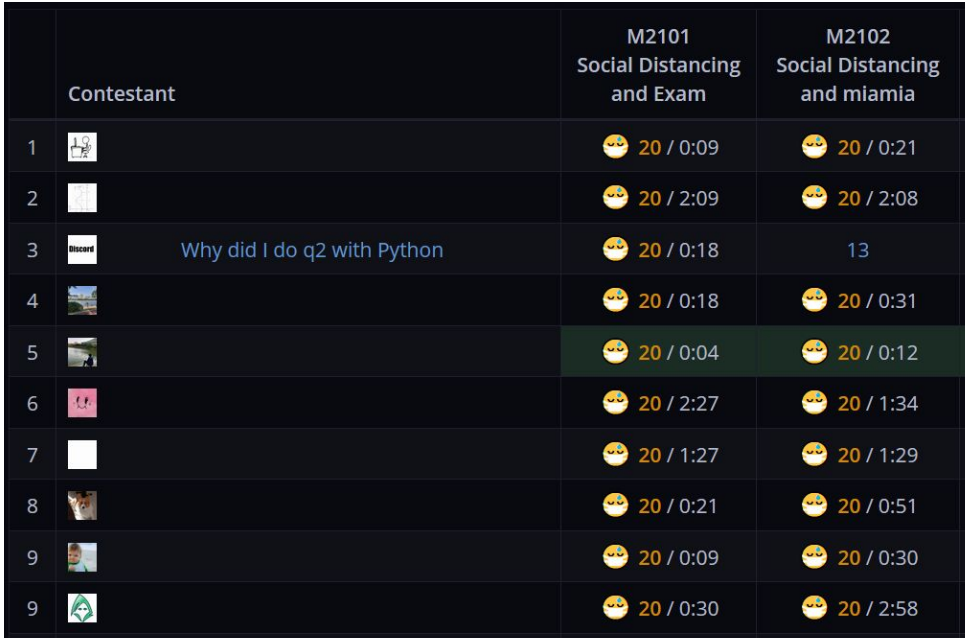
```
Output

4, July 1981
22, December 1981
18, October 1982
```

Solved with only 25 lines!

# M2102 Social Distancing and miamia

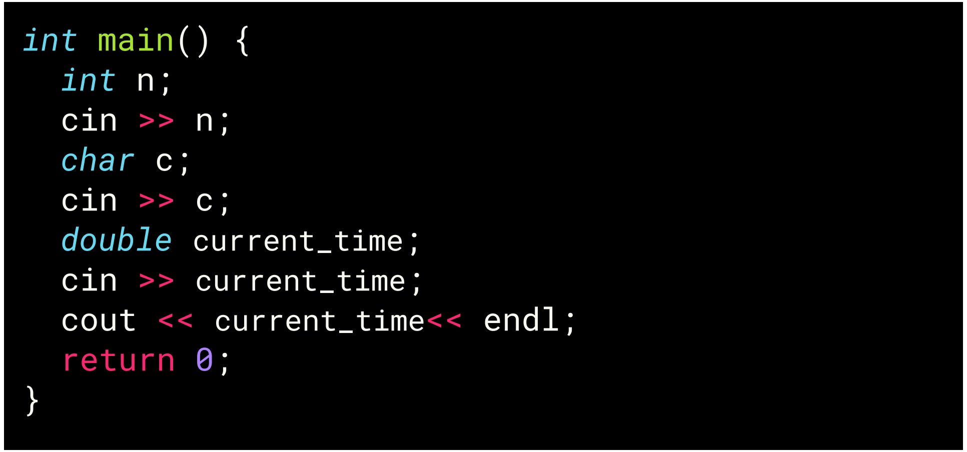
| Input | Output |
|---|---|
| 4<br>&1.2<br>(120)<br>{4}<br>1,,2,,3,,4,,8,,7,,6,,5,, | 9.200000 |
| 5<br>&1<br>(16<br>0){8}1,2,3,4,5,6,7,8,1,8,2,7<br>,{4}[1,8],[2,7],[3,6],(240)[4,5<br>], | 4.625000 |

# M2102 Social Distancing and miamia

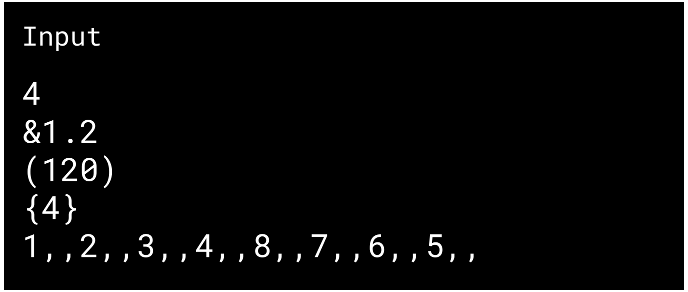


| | Contestant | M2101<br>Social Distancing<br>and Exam | M2102<br>Social Distancing<br>and miamia |
|---|---|---|---|
| 1 | | 😅 20 / 0:09 | 😅 20 / 0:21 |
| 2 | | 😅 20 / 2:09 | 😅 20 / 2:08 |
| 3 | Why did I do q2 with Python | 😅 20 / 0:18 | 13 |
| 4 | | 😅 20 / 0:18 | 😅 20 / 0:31 |
| 5 | | 😅 20 / 0:04 | 😅 20 / 0:12 |
| 6 | | 😅 20 / 2:27 | 😅 20 / 1:34 |
| 7 | | 😅 20 / 1:27 | 😅 20 / 1:29 |
| 8 | | 😅 20 / 0:21 | 😅 20 / 0:51 |
| 9 | | 😅 20 / 0:09 | 😅 20 / 0:30 |
| 9 | | 😅 20 / 0:30 | 😅 20 / 2:58 |

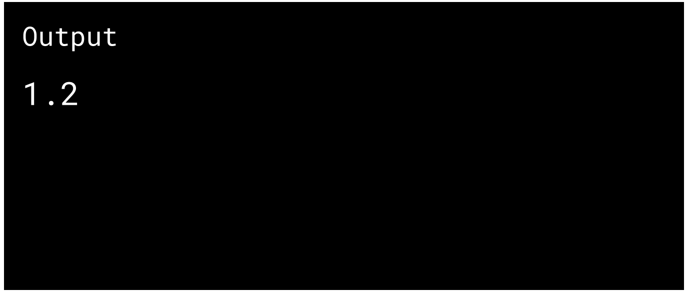
# Reading the start time



```cpp
int main() {
  int n;
  cin >> n;
  char c;
  cin >> c;
  double current_time;
  cin >> current_time;
  cout << current_time<< endl;
  return 0;
}
```



```
Input

4
&1.2
(120)
{4}
1,,2,,3,,4,,8,,7,,6,,5,,
```



```
Output

1.2
```

# Reading the rest of the data - Method 1

```
...
  string s;
  for (int i = 1; i < n; ++i) {
    string t;
    cin >> t;
    s += t;
  }
  cout << s << endl;
```

```
Input

4
&1.2
(120)
{4}
1,,2,,3,,4,,8,,7,,6,,5,,
```

```
Output

(120){4}1,,2,,3,,4,,8,,7,,6,,5,,
```

# Reading the rest of the data - Method 2

```
int main() {
  int n;
  cin >> n;
  char c;
  cin >> c;
  double current_time;
  cin >> current_time;
  string s = accumulate(istream_iterator<string>(cin),
                  istream_iterator<string>(), string());
  cout << s << endl;
  return 0;
}
```

End of stream

Empty string

```
Input

4
&1.2
(120)
{4}
1,,2,,3,,4,,8,,7,,6,,5,,
```

```
Output

(120){4}1,,2,,3,,4,,8,,7,,6,,5,,
```

Uses operator + to concatenate strings.

Note: press CTRL+Z (windows) / CTRL+D (linux) for end-of-file

accumulate

istream_iterator

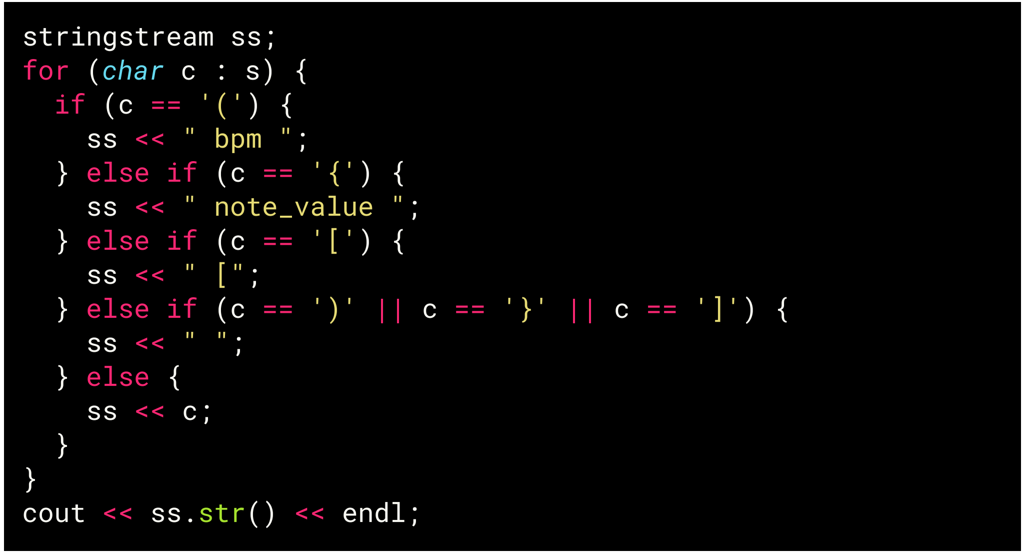
# Tokenize the input

Break down the string into space separated tokens.

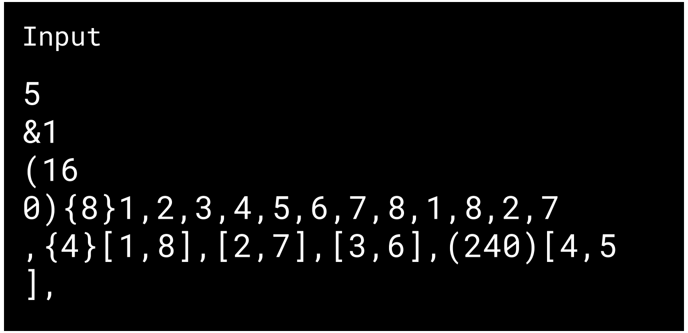
```
(120){4}1,,2,,3,,4,,8,,7,,6,,5,,
                    ↓
bpm 120 notevalue 4 1,,2,,3,,4,,8,,7,,6,,5
```

```
(160){8}1,2,3,4,5,6,7,8,1,8,2,7,{4}[1,8],[2,7],[3,6],(240)[4,5],
                    ↓
bpm 160 notevalue 8 1,2,3,4,5,6,7,8,1,8,2,7, notevalue 4 [1,8] ,
[2,7] , [3,6] , bpm 240 [4,5] ,
```

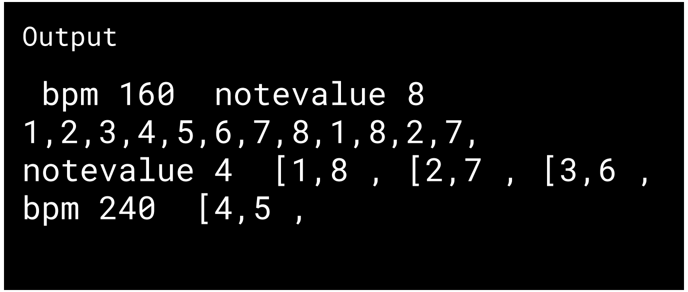
# Tokenize the input



```cpp
stringstream ss;
for (char c : s) {
  if (c == '(') {
    ss << " bpm ";
  } else if (c == '{') {
    ss << " note_value ";
  } else if (c == '[') {
    ss << " [";
  } else if (c == ')' || c == '}' || c == ']') {
    ss << " ";
  } else {
    ss << c;
  }
}
cout << ss.str() << endl;
```



```
Input

5
&1
(16
0){8}1,2,3,4,5,6,7,8,1,8,2,7
,{4}[1,8],[2,7],[3,6],(240)[4,5
],
```



```
Output

 bpm 160  notevalue 8
1,2,3,4,5,6,7,8,1,8,2,7,
notevalue 4  [1,8 , [2,7 , [3,6 ,
bpm 240  [4,5 ,
```

Change closing brackets to whitespace

stringstream

香港電腦奧林匹克競賽
Hong Kong Olympiad in Informatics

# Process BPM and note value

```cpp
double bpm = 0, note_value = 0;
while (!ss.eof()) {
  string token;
  ss >> token;
  if (token == "bpm") {
    ss >> bpm;
    cout << bpm << endl;
  } else if (token == "note_value") {
    ss >> note_value;
    cout << note_value << endl;
  }
}
```

stringstream is useful for type conversions

```
Input

5
&1
(16
0){8}1,2,3,4,5,6,7,8,1,8,2,7
,{4}[1,8],[2,7],[3,6],(240)[4,5
],
```

```
ss

 bpm 160  notevalue 8
1,2,3,4,5,6,7,8,1,8,2,7,
notevalue 4  [1,8 , [2,7 , [3,6 ,
bpm 240  [4,5 ,
```

```
Output

160
8
4
240
```

# Process beats and ignore brackets

```cpp
double bpm = 0, note_value = 0;
while (!ss.eof()) {
  string token;
  ss >> token;
  if (token == "bpm") {
    ss >> bpm;
  } else if (token == "note_value") {
    ss >> note_value;
  } else if (token[0] != '[') {
    int commas = count(token.begin(), token.end(), ',');
    current_time += commas * 240.0 / bpm / note_value;
  }
}
cout << fixed << setprecision(9) << current_time << endl;
```

Set to fixed point format (default = scientific notation)

Precision = 9 d.p. is sufficient.

```
Input

5
&1
(16
0){8}1,2,3,4,5,6,7,8,1,8,2,7
,{4}[1,8],[2,7],[3,6],(240)[4,5
],
```

```
ss

 bpm 160  notevalue 8
1,2,3,4,5,6,7,8,1,8,2,7,
notevalue 4  [1,8 , [2,7 , [3,6 ,
bpm 240  [4,5 ,
```

```
Output

4.625000000
```

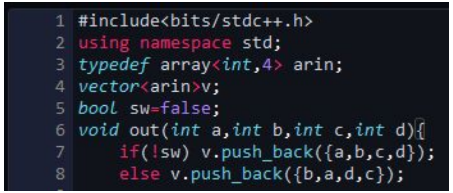
count fixed  setprecision

# Macros

Some competitive programmers use macros to shorten their code.

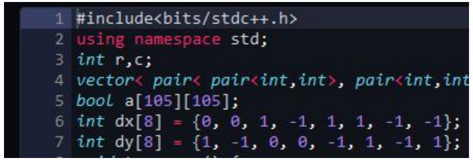
```
#define x first
#define y second
#define pii pair<int,int>
#define ll long long
#define pll pair<ll,ll>
#define pbb pair<bool,bool>
#define mp make_pair
#define pb push_back
#define pf push_front
#define popb pop_back
#define popf pop_front
#define xmod (ll)(1e9+7)
#define hmod 1286031825167LL
```

dxxxxxe

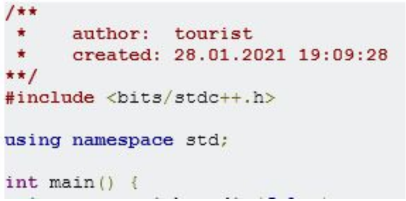


```
#include<bits/stdc++.h>
using namespace std;
typedef array<int,4> arin;
vector<arin>v;
bool sw=false;
void out(int a,int b,int c,int d){
    if(!sw) v.push_back({a,b,c,d});
    else v.push_back({b,a,d,c});
```

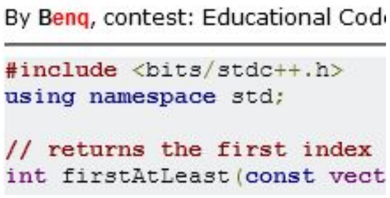
mxxxxxg



```
#include<bits/stdc++.h>
using namespace std;
int r,c;
vector< pair< pair<int,int>, pair<int,int
bool a[105][105];
int dx[8] = {0, 0, 1, -1, 1, 1, -1, -1};
int dy[8] = {1, -1, 0, 0, -1, 1, -1, 1};
```



```
/**
 *    author:  tourist
 *    created: 28.01.2021 19:09:28
**/
#include <bits/stdc++.h>

using namespace std;

int main() {
```



By Benq, contest: Educational Cod

```
#include <bits/stdc++.h>
using namespace std;

// returns the first index
int firstAtLeast(const vect
```

This is discouraged for several reasons:

- It makes code hard to read for others
- It makes the code longer (harder to find main)
- It is easy to introduce subtle bugs (e.g. missing parentheses: `#define sum(a, b) a + b`)
- It makes debugging harder

# Conclusion

Use a lot of library functions != Good programs

cppreference is your good friend

# Exercises

01007 Packet Re-assembly

01009 Words

M1902 Zero and Scheduling Problem

M2001 Corona and WFH

# Reference

https://en.cppreference.com

https://assets.hkoi.org/training2019/cpp.pdf

https://assets.hkoi.org/training2021/cpp.pdf