

10.1. Streams

10.2. Container Classes

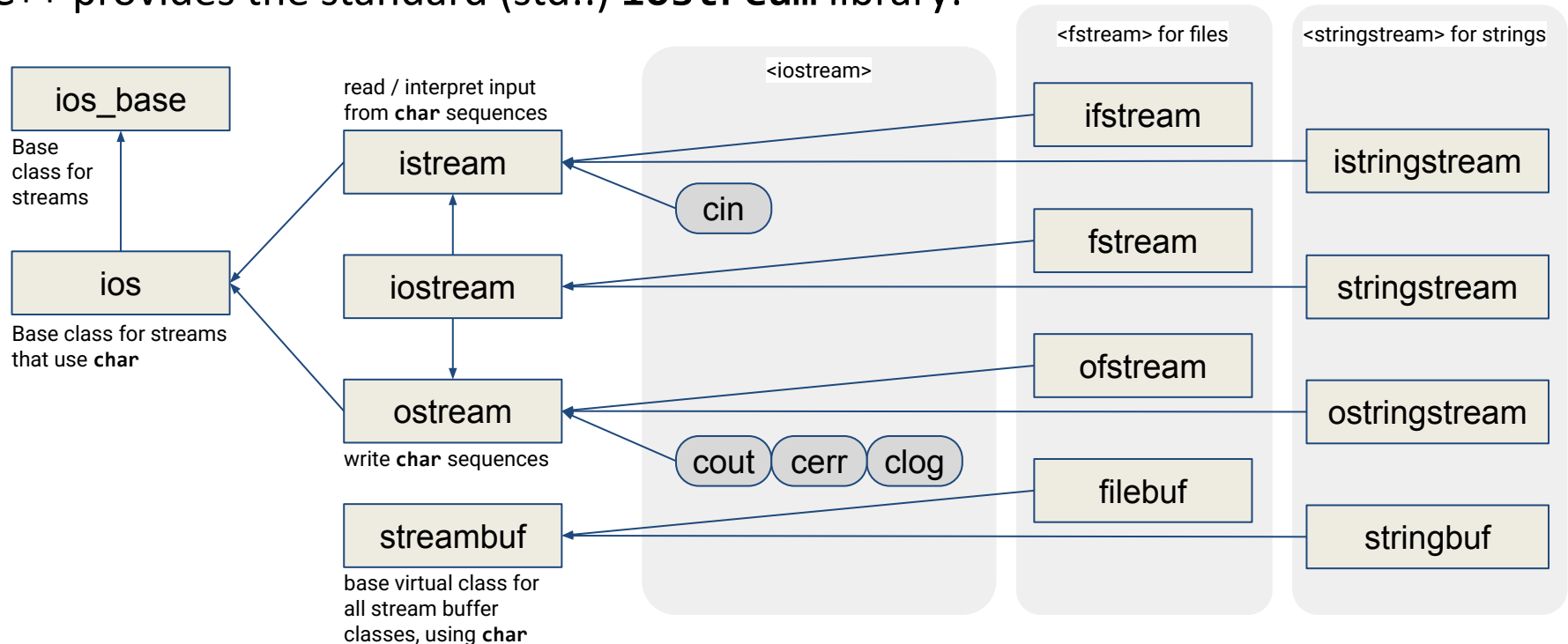
10.1. Streams

A stream class is a class which provides input and output functionality, as a standard abstraction across devices where input and output operations are performed. A stream can be represented as a source or destination, of characters of indefinite length.

For examples sending characters to and receiving characters from ...
disk files, the keyboard and the console, a network connection

10.1. Streams

C++ provides the standard (std::) **iostream** library:



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std::streambuf buffers manage the actual buffer on a lower level, with methods such as **overflow()** to handle output (writing), **underflow()** to handle input (reading), or **sync()** to flush data.

std::iostream Streams wrap a **std::streambuf** buffer, providing several common methods and operators, including:

- **get / put** a single character from/to a stream before returning
- **read / write** a certain amount of data from/to a stream before returning
- **getline** reads characters from an input stream until a delimiter character (usually `'\n'` is found) and places them into a string
- stream insertion operator `<<` for output to the stream
- stream extraction operator `>>` for input to the stream

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Example 00 (difficulty level: 🌶️🌶️🌶️): Install [boost](#) and compile:

```
/* change the following code to output the server reply straight to a local html file
   and add exception handling in case of file or connection problems */
#include <fstream>
#include <boost/asio.hpp>

int main() {
    char reply[4096];
    boost::asio::ip::tcp::iostream socket("www.example.com", "http"); // socket stream
    std::ofstream outputFile("myTest.txt"); // stream to output file
    socket << "GET / HTTP/1.1\r\nHost: www.example.com\r\nConnection: Close\r\n\r\n";
    socket << std::flush;
    socket.read(reply, 4096);
    outputFile << "Reply of server:\n" << reply; // output reply of server to text file
}
```

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Example 01 (difficulty level: 🌶️🌶️🌶️):

```
/* An example of dynamically transforming output (similar to filters in Boost) */
#include <iostream>

class Uppercase : public std::streambuf { // Class for a custom stream buffer
    std::streambuf* target;
public:
    Uppercase(std::streambuf* buf) : target(buf) {}
protected:
    // overflow is virtual std::streambuf function, called by stream writing a char:
    int overflow(int ch) override {
        if (ch != EOF) ch = std::toupper(ch); return target->sputc( ch );
    }
};

int main() {
    Uppercase u( std::cout.rdbuf() ); // buffer links to cout
    std::ostream upperOutput( &u ); // output stream using u
    upperOutput << "this should be uppercase\n";
}
```

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Example 02 (difficulty level: 🌶️🌶️🌶️):

```
/* Implement the two override methods of RLEstreambuf to implement a basic run
length encoding compression of a string being sent to an output stream. The
output of the program below should give "6A5B2CD2A6C3A".
Note that EOF is a special terminator character that should not be handled.
Use sputc() to write characters, and '0'+count to write the ascii digits. */
#include <iostream>

class RLEstreambuf : public std::streambuf { // Class for a custom stream buffer
public:
    RLEstreambuf(std::streambuf* dest) : dest(dest), last_char(EOF), count(0) {}
protected:
    int overflow(int ch) override; // override overflow to handle the compression
    int sync() override; // flush last data (last character) when done
private:
    std::streambuf* target;
    int last_char; // previous character
    int count; // count of consecutive same characters
};
```

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Example 02 (difficulty level: 🌶️🌶️🌶️):

```
int main() {  
    RLEstreambuf rleBuf(std::cout.rdbuf());  
    std::ostream rleOut(&rleBuf);  
    std::string input = "AAAAAABBBBBCCDAACCCCCCA"; // Input string to compress  
    rleOut << input; // the output is automatically RLE compressed  
    rleOut.flush(); // flush leads to sync being called to output last character  
    std::cout << '\n';  
}
```


10.2. Container Classes

A container class is a class which implements a data structure containing objects of other classes, with well-defined access patterns (e.g., inserting, finding, removing, or sorting objects), independent of the type of objects stored inside.

Examples: Array, Stack, Queue, List, Tree

10.2. Container Classes

Illustration of a container: A queue of predefined size for integers

```
class Queue { // Class for a queue of integers
public:
    Queue(int size = 100) : maxSize(size), tail(0), head(0), filled(0) { items = new int[size]; }
    ~Queue() { delete[] items; items = nullptr; };
    void put(int data);
    int get();
    bool isFull() const { return filled == maxSize; }
    bool isEmpty() const { return filled == 0; }
    void clear() { filled = 0; head = 0; tail = 0; } // clear whole queue
private:
    int * items; // array of integers
    int maxSize; // size of items
    int tail; // position in array to put
    int head; // position in array to get from
    int filled; // number of elements in queue
};
```

10.2. Container Classes

Illustration of a container: A queue of predefined size for integers

```
// put element at the tail of the queue, for example put(17) updates:
// items: [ ][ ][ ][ ][ ][17][ ] ... [ ][ ]
//           head           tail→
void Queue::put(int data) { // put element at tail
    if (!isFull()) {
        items[tail] = data;
        tail = (tail+1) % maxSize;
        filled++;
    } else {
        throw std::runtime_error("queue: full on put");
    }
}
```

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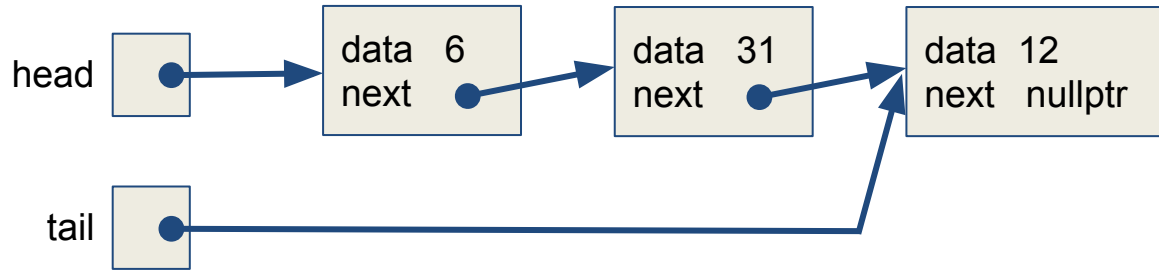
Illustration of a container: A queue of predefined size for integers

```
// gets element at the head of the queue, for example get() updates:
// items:  [ ][ ][ ][ ][ ][ ][ ] ... [ ][ ]
//           head→           tail
int Queue::get() { // get and remove element from head
    int retval;
    if (!isEmpty()) {
        retval = items[head];
        head = (head+1) % maxSize;
        filled--;
    } else {
        throw std::runtime_error("queue: empty on get");
    }
    return retval;
}
```

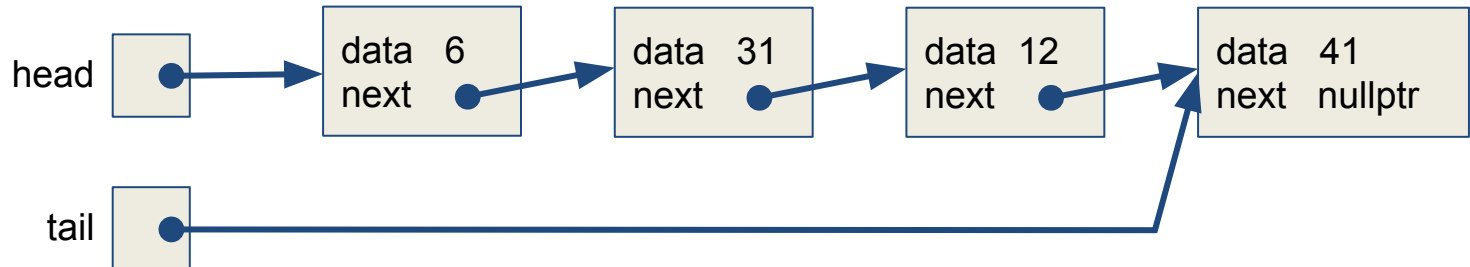
10.2. Container Classes

Illustration of a container: A queue of unlimited size for **QueueElements**

```
UQueue q;  
q.put(6);  
q.put(31);  
q.put(12);
```



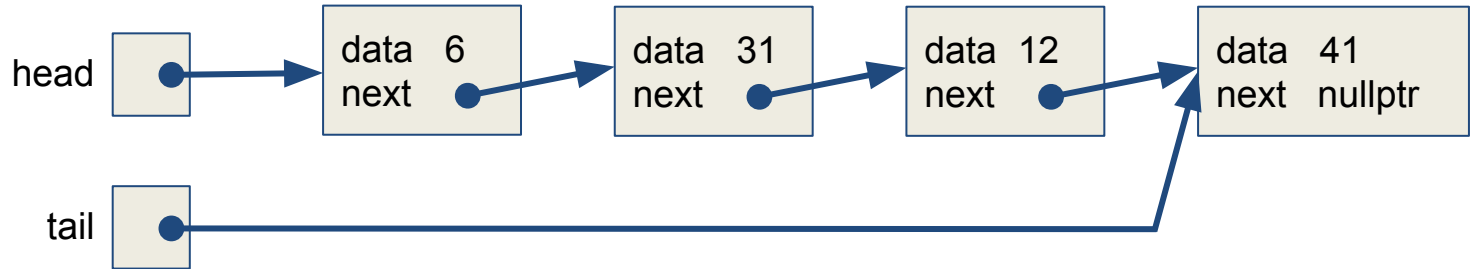
```
q.put(41);
```



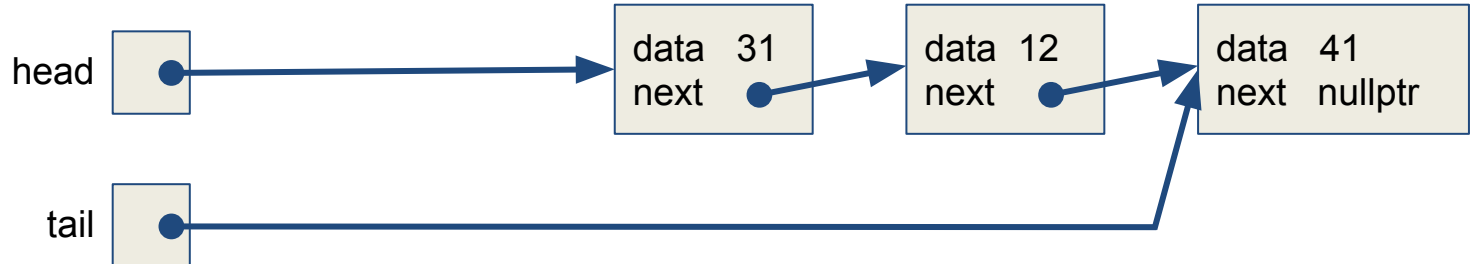
10.2. Container Classes

Illustration of a container: A queue of unlimited size for **QueueElements**

```
q.put(41);
```



```
int v;  
v = q.get();
```



10.2. Container Classes

Illustration of a container: A queue of unlimited size for **QueueElements**

```
class QueueElement; // declaration of the element class

class UQueue { // Class for an unlimited queue of QueueElements
public:
    UQueue() { head = tail = nullptr; }
    ~UQueue() { clear(); };
    void put(int data);
    int get();
    bool isEmpty() const;
    void clear();
private:
    QueueElement * head; // pointer to element to put
    QueueElement * tail; // pointer to element to get from
};
```

10.2. Container Classes

Illustration of a container: A queue of unlimited size for **QueueElements**

```
class QueueElement { // element class, hidden from users
public:
    QueueElement(int data) : data(data) , next(nullptr) {}
    int data;
    QueueElement * next;
};

void UQueue::clear() { // iteratively clear the queue of all elements
    QueueElement * elem, * elem_next;
    for (elem = head; elem != nullptr; elem = elem_next) {
        elem_next = elem->next;
        delete elem;
    }
    head = tail = nullptr;
}
```


10.2. Container Classes

Illustration of a container: A queue of unlimited size for **QueueElements**

```
bool UQueue::isEmpty() const { // check whether the queue is empty
    return head == nullptr;
}

void UQueue::put(int data) { // put in new data element at tail
    QueueElement * node = new QueueElement(data);
    if ( isEmpty() ) {
        head = tail = node;
    } else {
        tail = tail->next = node; // tail is guaranteed to be valid
    }
}
```

10.2. Container Classes

Illustration of a container: A queue of unlimited size for **QueueElements**

```
int UQueue::get() { // get and remove element from head
    int retVal;
    if ( !isEmpty() ) {
        retVal = head->data;
        QueueElement * second = head->next;
        delete head;
        head = second;
    } else {
        throw std::runtime_error("uqueue: empty on get");
    }
    return retVal;
}
```

10. Streams and Container Classes

10.2. Container Classes: Sequence Containers

Sequence Containers maintain the order of elements:

- **`std::vector`** for dynamic arrays. Use this when you need fast access of any element, and efficient append operations at end of the vector.
- **`std::deque`** for double-ended queues. Use this when you need fast inserts and removals at both ends of the queue.
- **`std::list`** for doubly-linked lists. Use this for fast insertions and deletions anywhere in the list.
- **`std::forward_list`** for singly-linked list. Use this for light-weight lists that only need forward iterations.
- **`std::array`** Fixed-size array on the stack (no heap). Use this when the size is known at compile time.

10. Streams and Container Classes

10.2. Container Classes: Associative Containers

Associative Containers maintain sorted key-based element collections:

- **`std::set`** for sorted, unique elements. Use this when elements are unique and must remain ordered.
- **`std::multiset`** for any sorted elements. Use this when elements can be duplicates and need to be ordered.
- **`std::map`** for key-value pairs that are sorted by unique keys. Use this when it makes sense to have each element linked to its key.
- **`std::multimap`** for key-value pairs that are sorted by keys. Use this when elements can be grouped under the same keys.

10. Streams and Container Classes

10.2. Container Classes: Unordered Associative Containers

Unordered Associative Containers maintain *hash-based* collections:

- **`std::unordered_set`** for unique elements. Use this when elements are unique and order is not needed.
- **`std::unordered_multiset`** for any elements. Use this when elements can be duplicates and need to be ordered.
- **`std::unordered_map`** for key-value pairs, hash-based, with unique keys. Use this when it makes sense to have each element linked to its key and they do not need to be sorted.
- **`std::unordered_multimap`** for key-value pairs, hash-based. Use this when elements do not need to be ordered and can be grouped under the same keys.

10.2. Container Classes: Container Adapters

Container Adapters are wrappers for other containers to limit their interfaces.

- **`std::stack`** for last-in, first-out (LIFO) access of typically **deque**s
- **`std::queue`** for first-in, first-out (FIFO) access of typically **deque**s
- **`std::priority_queue`** for elements that are kept in sorted priority order (typically using **vector** with heap)

10.2. Container Classes

Example of a container: `std::multiset`

```
#include <iostream>
#include <set>
int main() {
    std::multiset<double> grades; // the multiset to record grades
    // inserting student grades in any order, with duplicates:
    grades.insert(1.7); grades.insert(2.3); grades.insert(1.0);
    grades.insert(2.3); grades.insert(5.0); grades.insert(2.3);
    grades.insert(4.0); grades.insert(1.0); grades.insert(5.0);
    std::cout << "all grades sorted:\n";
    for (auto grade : grades) std::cout << grade << ' ';
    // count how often certain grades occurred:
    std::cout << "\ngrade 5.0 was given " << grades.count(5.0) << " times.";
    std::cout << "\ngrade 2.3 was given " << grades.count(2.3) << " times.";
    // erase all 5.0 grades:
    grades.erase(5.0);
    std::cout << "\nall passing grades:\n";
    for (auto grade : grades) std::cout << grade << ' ';
    std::cout << '\n';
}
```

10.2. Container Classes

Example of a container: `std::priority_queue`

```
#include <iostream>
int main() {
    // a package has a weight and destination, deliveries are a priority queue
    using Package = std::tuple<double, std::string>;
    // Comparator for max-heap (heavier packages have higher priority):
    auto cmp = [](const Package & a, const Package & b) {
        return std::get<0>(a) < std::get<0>(b); // index-based access
    };
    std::priority_queue<Package, std::vector<Package>, decltype(cmp)> deliveries(cmp);
    // add deliveries, duplicates possible:
    deliveries.push({2.5, "Berlin"}); deliveries.push({1.2, "Siegen"});
    deliveries.push({3.1, "Berlin"}); deliveries.push({2.5, "Hamburg"});
    deliveries.push({4.1, "Cologne"}); deliveries.push({2.5, "Berlin"});
    // emptying the priority queue:
    std::cout << "handling all deliveries (packages sorted by weight):\n";
    while (!deliveries.empty()) {
        auto [weight, city] = deliveries.top(); // structured binding
        std::cout << weight << " kg - " << city << '\n';
        deliveries.pop();
    }
}
```


10.2. Container Classes

`comparison.cpp`

```
// create three containers, unordered_set, vector, and forward_list:
std::unordered_set<int> u_set(data.begin(), data.end());
std::vector<int> vec(data.begin(), data.end());
std::forward_list<int> f_list(data.begin(), data.end());

std::cout << "Timing element lookup:\n";
benchmark("unordered_set", u_set, queries, [](const auto & c, int x) {
    return c.find(x) != c.end();
});
benchmark("vector", vec, queries, [](const auto & c, int x) {
    return std::find(c.begin(), c.end(), x) != c.end();
});
benchmark("forward_list", f_list, queries, [](const auto & c, int x) {
    return std::find(c.begin(), c.end(), x) != c.end();
});
```