IN2029: Programming in C++

Session 2 – Sequential containers

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This session

We'll be writing some programs that operate on batches of data, which allows us to explore

- a bit more about streams
- the standard idiom for looping to the end of an input stream
- manipulators
- vectors from the standard template library
- introduction to containers

Calculating statistics from a list of numbers

Task: read in a list of numbers and print their average.

The overall structure of our program will be:

```
#include <iostream>
#include <iomanip>

using namespace std;

int main() {
    // ... read in data ...
    // ... print results ...
    return 0;
}
```

Reading the data

The first part is to read all the numbers and record their count and sum:

```
cout << "Please enter a series of numbers\n";

// the number and total of values read
int count = 0;
double sum = 0;

// read values from standard input
double x; // a variable for reading into
while (cin >> x) {
    ++count;
    sum += x;
}
```

Library details: testing for end-of-input

We have already seen that the **>>** operator returns the input stream, in statements like

```
cin >> x >> y >> z;
```

The result of **>>** can also be used in a test, as in the common idiom for reading a series of things and testing for the end of the input:

```
while (cin >> x) {
    // .. do something with x
}
```

Testing a stream yields `true` if the last operation on the stream succeeded, and `false` if it didn't.

This idiom is much more robust than separately testing for eof.

(You can indicate end of input on the console by typing Control-Z Return on Windows, or Control-D on Unix.)

Alternative: reading from a file

If we want to read from a file instead of the standard input, we use an **ifstream** (a different kind of **istream**). At the top of the file, we need to include another header:

```
#include <fstream>
```

Then we declare a variable **in** of type **istream**, with the file name as a parameter, and then read from that instead of **cin**:

```
    // read values from a file
    ifstream in("values.txt");
    double x;
    while (in >> x) {
        ++count;
        sum += x;
    }
```

Breaking the input into words

An example reading strings:

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

using namespace std;

int main() {
    string s;
    while (cin >> s)
        cout << s << '\n';
    return 0;
}
```

Recall that the **>>** operator on strings reads words.

reading a line including spaces

If we want to read a string containing spaces from standard input or from a file, we use a **getline** function. At the top of the file, we need to include this header:

```
#include <iostream>
```

For reading from a file, use **getline(in,line)**, for reading from standard input use **getline(cin,line)**, you need to define **line** as a **string** and **in** should be defined as an **ifstream**:

```
    // read values from a file
    ifstream in("values.txt");
    string line;
    while (getline(in,line)) {//or you can use getline(cin,line)
        //...
    }
```

Language details: `i++` vs `++i`

The following statements all increase an `int` variable `i` by one:

```
    i = i+1;
    i += 1;
    i++;
    ++i;
```

The difference between the last two is only seen when the value of the expression is used:

```
    int i = 5;
    int j = ++i; // j is set to 6; i is now 6
    int k = i++; // k is also set to 6; i is now 7
```

- `i++` returns the value before incrementing (so the old value has to be saved somewhere, which could be expensive with some types)
- `++i` returns the value after incrementing (simpler)

Printing the results

Finally, we want to print the results:

```
    cout << count << " numbers\n";
    if (count > 0) {
        cout << "average = " << sum/count << '\n';
    }
```

By default, floating point numbers are printed with up to 5 significant figures, but we can change that:

```
        cout << "average = " << setprecision(3) <<
            sum/count << '\n';
```

Library details: manipulators

`setprecision(3)` is an example of a stream manipulator (from the **`<iomanip>`** system header), like **`flush`** or **`endl`**: a special kind of object with an overloading of the **`<<`** operator than changes the state of the stream.
This manipulator is used to adjust formatting:

```
    cout << setprecision(3);
```

doesn’t do any output, but it sets the precision for any following output.

```
    cout << setprecision(3) << x << setprecision(5) << y;
```

Other manipulators set base, paddings, etc.

Cleaning up

- We have used **`setprecision`** to set the maximum number of significant figures to what we want.
- Nothing else is happening in this program, but in general it would be polite to set the precision back to what it was before.
- We can get the current precision using **`cout.precision()`**.

This yields our final version:

```
int prec = cout.precision();
cout << "average = " << setprecision(3) <<
    sum/count << setprecision(prec) << '\n';
```

Calculating a different statistic

Task: read in a list of numbers and print their median.

The median of a collection of numbers is the “middle” value when they are arranged in order:

$$1\ 3\ 3\ 7\ 10\ \boxed{11}\ 11\ 13\ 14\ 15\ 15$$

However, the input data may be in any order.

- Unlike computing the average, to compute the median we will need to store all the numbers until the end of the program. We shall use a `vector` to do this.
- Then we need to arrange the values in order. We shall use the library function `sort`.
- Then the median will be the middle value in the vector.

Outline

The overall structure of our program will be:

```
#include <iostream>
#include <vector>
#include <algorithm>

using namespace std;

int main() {
    // ... read and store the data ...
    // ... sort the data ...
    // ... print the middle value ...
    return 0;
}
```

Vectors

```
#include <vector>
```

C++ has arrays, but we'll use vectors instead (a container like `ArrayList` in Java, except that a variable of **`vector`** type holds an object, not a reference):

```
    vector<int> vi;  // empty vector of ints
    vector<string> vs;  // empty vector of strings
```

Vectors also be extended:

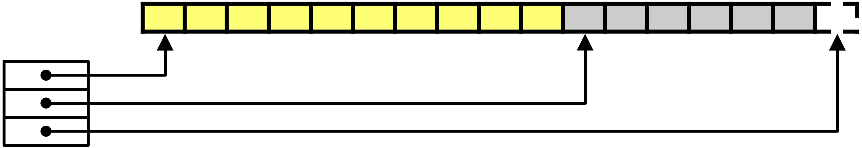
```
    vs.push_back(s);
```

The current length of **`vs`** is **`vs.size()`**
Vectors can be accessed just like arrays (indices 0 . . . **`size()-1`**):

```
    vi[1] = x;
    vi[2] = vi[1] + 3;
```

Implementation of vectors

Internally, vectors are implemented as extensible arrays (see session 3 of Data Structures and Algorithms). One possible implementation is:



The precise internals do not concern us here.

We need only use the provided operations, confident that they are *very* carefully engineered.

Reading the data into a vector

We start by reading all the numbers and storing them in a vector:

```
cout << "Please enter a series of numbers\n";

// read numbers from the standard input
// and store them in a vector
vector<double> v;
double x;
while (cin >> x)
    v.push_back(x);
```

We don't need a separate variable to count them: we can use `v.size()`.

Finding the median: outline

- Only a non-empty vector can have a median.
- First, we need to sort the vector.

```
// compute and output results
unsigned n = v.size();
cout << n << " numbers\n";
if (n > 0) {
    // sort the whole vector
    sort(v.begin(), v.end());

    // ... find the middle value
}
```

Language details: unsigned types

C++ has signed and unsigned integral types of various sizes:

Signed	?	Unsigned
`signed char`	`char`	`unsigned char`
`short`		`unsigned short`
`int`		`unsigned int` (or `unsigned`)
`long`		`unsigned long`
`long long`		`unsigned long long` (in C++11)

- Unlike in Java, the sizes are not defined by the standard (but they are non-decreasing).
- `char` may be either a signed or unsigned type, whichever is more efficient on this architecture.
- Unsigned types cannot be negative: if `i` is of unsigned type, `i < 0` can never be `true`.

Unsigned types: caution

- Unsigned integers will silently underflow:

```
unsigned i = 0;
i--;
```

will not fail – it will set `i` to a very large positive number.

- If an operation involves both a signed and unsigned type, it will silently convert the signed type to unsigned first, so in

```
int i = -5;
unsigned j = 1;
if (i < j)
```

the last test will fail, because `-5` will be silently converted to a very large positive number.

The type of `size()`

- Containers cannot have negative size.
- The return type of the `size()` member function is an unsigned type, but *which* unsigned type is implementation dependent.
- The portable name of its type is `vector<double>::size_type`.
- Here `::` selects a static attribute of the type `vector<double>`. (This is a different use of `::` from namespace qualification, as in `std::vector`.)
- We can use this as the type of the variable `n`:

```
vector<double>::size_type n = v.size();
```

Library details: `sort`, `begin`, `end`

```
sort(v.begin(), v.end());
```

- To sort a vector, we use the **`sort`** function, declared in the **`<algorithm>`** system header.
- Instead of a container, **`sort`** takes two positions or iterators (which we'll explore in session 4).
- These positions should be in the same container, with the first before the second.

- The vector class has member functions **`begin()`** and **`end()`**, yielding positions as the start and end of the vector.
- So the above statement sorts the whole vector – a common idiom, but using iterators is more general.

Where is the median?

There are two cases:

- odd number of elements, e.g. 9:

	0	1	2	3	**4**	5	6	7	8
`v`									

  middle element is cell 4, *i.e.* **`v[v.size()/2]`**

- even number of elements, e.g. 8:

	0	1	2	**3**	**4**	5	6	7
`v`								

  In this case we average the two middle elements (cells 3 and 4):

```
(v[v.size()/2 - 1] + v[v.size()/2])/2
```

Computing the median

We use this plan to compute the median of the sorted array:

```
// find the middle value
vector<double>::size_type middle = n/2;
double median;
if (n%2 == 1) // size is odd
    median = v[middle];
else // size is even
    median = (v[middle-1] + v[middle])/2;
cout << "median = " << median << '\n';
```

and our program is complete.

Type aliases

In C++11, we can declare a new name for a type: A `typedef` declaration allows us to introduce a new name for a type:

```
using vec_size = vector<double>::size_type;
```

This defines a new type name `vec_size` that is equivalent to the longer name. One use is to avoid repeating a long type name:

```
vec_size n = v.size();
// ...
    vec_size middle = n/2;
```

Older versions of C++ used the `typedef` declaration, with exactly the same effect:

```
typedef vector<double>::size_type vec_size;
```

C++11 shortcut: `auto`

In C++, we can just use `auto` instead of the type, which tells the compiler that the variable has the type of the initializing expression:

```
    auto n = v.size();
    // ...
    auto middle = n/2;
```

Here `n` has type `vector<double>::size_type`, and `middle` also has an unsigned type.

- A variable declared as `auto` must be initialized.
- The variable still has a type, which determines how it can be used, and what operations on the variable mean, it's just implicit.

Prefer `auto` to explicit type declarations (if there is an initializing expression with the desired type).

Vectors: further points

- A vector variable contains a whole vector:

```
vector<int> v1 = v; // copy the vector
sort(v.begin(), v.end());
```

  results in **v** being sorted, but **v1** still containing a copy of the original unsorted **v**.
- When indexing **v[i]**, the index **i** is not checked: if it is out of range, the program may crash or continue with corrupted data.
- Other vector member functions:

back()	returns the last element of the vector
pop_back()	removes the last element of the vector

Another container: **deque**

Deques (double-ended queues) can be created in a similar way:

```
deque<int> d; // an empty deque
```

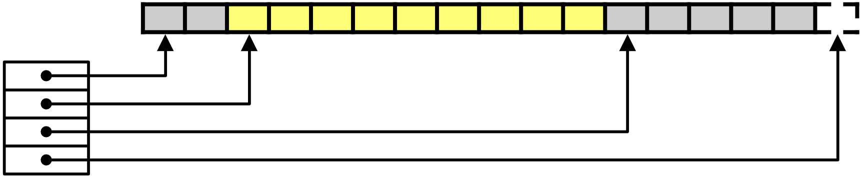
Deques support indexing with `[]`, and these member functions:

size()	the number of elements in the deque
push_back(x)	add **x** to the back of the deque
back()	returns the last element of the deque
pop_back()	removes the last element of the deque
push_front(x)	add **x** to the front of the deque
front()	returns the first element of the deque
pop_front()	removes the first element of the deque

There are common names with **vector**, but no inheritance.

Implementation of deques

Deques are also implemented as extensible arrays, but unlike vectors their front end can also move. One possible implementation is:



Once again, we just use the provided operations, relying on the carefully tuned implementation.

Another container: `stack`

Stacks can be created in a similar way:

```
stack<int> s; // an empty stack
```

Stacks do not support indexing with `[]`, but support these member functions:

size() the number of elements in the stack

push(x) add `x` to the top of the stack

top() returns the last element (on top) of the stack

pop() removes the last element of the stack

Queues are very similar to stacks: (size(), push(x), front() and pop())

```
queue<int> q; // an empty queue
```

Next week

- Functions in C++ allow us to structure and reuse code.
- Passing parameters by value (like in Java) involves copying, which can be expensive as in C++ (unlike in Java) variables contain whole objects.
- Passing parameters by reference avoids copying, and is heavily used in C++.
- It is good practice to use `const` qualifiers to declare that you're not changing something.