Chapter 4
Computation

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Abstract

- Today, I'll present the basics of computation. In particular, we'll discuss expressions, how to iterate over a series of values ("iteration"), and select between two alternative actions ("selection"). I'll also show how a particular sub-computation can be named and specified separately as a function. To be able to perform more realistic computations, I will introduce the **vector** type to hold sequences of values.
- Selection, Iteration, Function, Vector

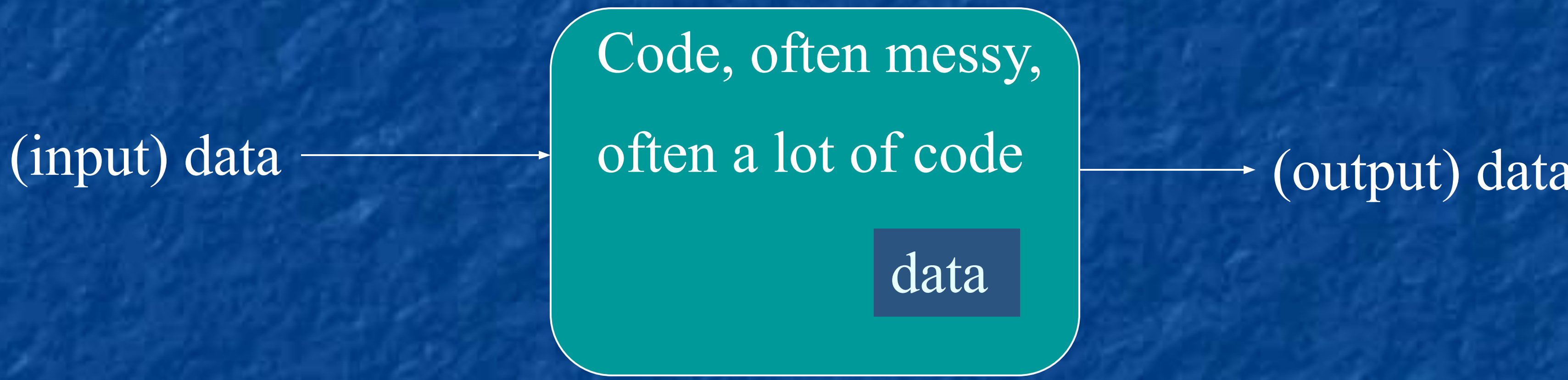
Overview

- Computation
  - What is computable? How best to compute it?
  - Abstractions, algorithms, heuristics, data structures
- Language constructs and ideas
  - Sequential order of execution
  - Expressions and Statements
  - Selection
  - Iteration
  - Functions
  - Vectors

You already know most of this

- Note:
  - You know how to do arithmetic
    - d = a+b*c
  - You know how to select
    "if this is true, do that; otherwise do something else "
  - You know how to "iterate"
    - "do this until you are finished"
    - "do that 100 times"
  - You know how to do functions
    - "go ask Joe and bring back the answer"
    - "hey Joe, calculate this for me and send me the answer"
- What I will show you today is mostly just vocabulary and syntax for what you already know

Computation



- Input: from keyboard, files, other input devices, other programs, other parts of a program
- Computation – what our program will do with the input to produce the output.
- Output: to screen, files, other output devices, other programs, other parts of a program

Computation

- Our job is to express computations
  - Correctly
  - Simply
  - Efficiently
- One tool is called Divide and Conquer
  - to break up big computations into many little ones
- Another tool is Abstraction
  - Provide a higher-level concept that hides detail
- Organization of data is often the key to good code
  - Input/output formats
  - Protocols
  - Data structures
- Note the emphasis on structure and organization
  - You don't get good code just by writing a lot of statements

Language features

- Each programming language feature exists to express a fundamental idea
  - For example
    - + : addition
    - * : multiplication
    - **if (*expression*) *statement* else *statement* ;** selection
    - **while (*expression*) *statement* ;** iteration
    - **f(x);** function/operation
    - …
- We combine language features to create programs

Expressions

```
// compute area:
int length = 20;          // the simplest expression: a literal (here, 20)
                          // (here used to initialize a variable)
int width = 40;
int area = length*width;         // a multiplication
int average = (length+width)/2;  // addition and division
```

The usual rules of precedence apply:

a*b+c/d means **(a*b)+(c/d)** and not **a*(b+c)/d**.

If in doubt, parenthesize. If complicated, parenthesize.

Don't write "absurdly complicated" expressions:

```
a*b+c/d*(e-f/g)/h+7          // too complicated
```

Choose meaningful names.

Expressions

- Expressions are made out of operators and operands
  - Operators specify what is to be done
  - Operands specify the data for the operators to work with
- Boolean type: **bool** (**true** and **false**)
  - Equality operators: = = (equal), **!=** (not equal)
  - Logical operators: **&&** (and), || (or), **!** (not)
  - Relational operators: < (less than), > (greater than), <=, >=
- Character type: **char** (e.g., **'a'**, **'7'**, and **'@'**)
- Integer types: **short, int, long**
  - arithmetic operators: +**, -,** *, /, **%** (remainder)
- Floating-point types: e.g., **float, double** (e.g., **12.45** and **1.234e3**)
  - arithmetic operators: +**, -,** *, /

Concise Operators

- For many binary operators, there are (roughly) equivalent more concise operators
  - For example
    - **a += c** means **a = a+c**
    - **a *= scale** means **a = a*scale**
    - **++a** means **a += 1**
      or **a = a+1**
  - "Concise operators" are generally better to use (clearer, express an idea more directly)

Statements

- A statement is
  - an expression followed by a semicolon, or
  - a declaration, or
  - a “control statement” that determines the flow of control
- For example
  - **a = b;**
  - **double d2 = 2.5;**
  - **if (x == 2) y = 4;**
  - **while (cin >> number) numbers.push_back(number);**
  - **int average = (length+width)/2;**
  - **return x;**
- You may not understand all of these just now, but you will …

Selection

- Sometimes we must select between alternatives
- For example, suppose we want to identify the larger of two values. We can do this with an **if** statement

```
if (a<b)        // Note:  No semicolon here
    max = b;
else            // Note:  No semicolon here
    max = a;
```

- The syntax is

```
if (condition)
    statement-1     // if the condition is true, do statement-1
else
    statement-2     // if not, do statement-2
```

Iteration (while loop)

- The world's first "real program" running on a stored-program computer (David Wheeler, Cambridge, May 6, 1949)

```
// calculate and print a table of squares 0-99:
int main()
{
    int i = 0;
    while (i<100) {
        cout << i << '\t' << square(i) << '\n';
        ++i ;       // increment i
    }
}
// (No, it wasn't actually written in C++ ☺ .)
```

Iteration (while loop)

- What it takes
  - A loop variable (control variable); here: **i**
  - Initialize the control variable; here: **int i = 0**
  - A termination criterion; here: if **i<100** is false, terminate
  - Increment the control variable; here: **++i**
  - Something to do for each iteration; here: **cout << …**

```
int i = 0;
while (i<100) {
    cout << i << '\t' << square(i) << '\n';
    ++i ;      // increment i
}
```

Iteration (for loop)

- Another iteration form: the **for** loop
- You can collect all the control information in one place, at the top, where it's easy to see

```
for (int i = 0; i<100; ++i) {
    cout << i << '\t' << square(i) << '\n';
}
```

That is,

for (initialize; condition ; increment)
controlled statement

Note: what is **square(i)**?

Functions

- But what was **square(i)?**
  - A call of the function **square()**

```
int square(int x)
{
    return x*x;
}
```

  - We define a function when we want to separate a computation because it
    - is logically separate
    - makes the program text clearer (by naming the computation)
    - is useful in more than one place in our program
    - eases testing, distribution of labor, and maintenance

Control Flow


```
int main()
{
        i=0;

    while (i<100)
    {

        square(i)

    }
}
```

i<100

i==100

```
int square(int x)
{

    return x * x;
}
```

Functions

- Our function

```
int square(int x)
{
   return x*x;
}
```

is an example of

```
Return_type  function_name ( Parameter list )
                        // (type name, etc.)
{
   // use each parameter in code
   return some_value;          // of Return_type
}
```

Another Example

- Earlier we looked at code to find the larger of two values. Here is a function that compares the two values and returns the larger value.

```
int max(int a, int b)  // this function takes 2 parameters
{
        if (a<b)
                return b;
        else
                return a;
    }

    int x = max(7, 9);       // x becomes 9
    int y = max(19, -27);    // y becomes 19
    int z = max(20, 20);     // z becomes 20
```

Data for Iteration - Vector

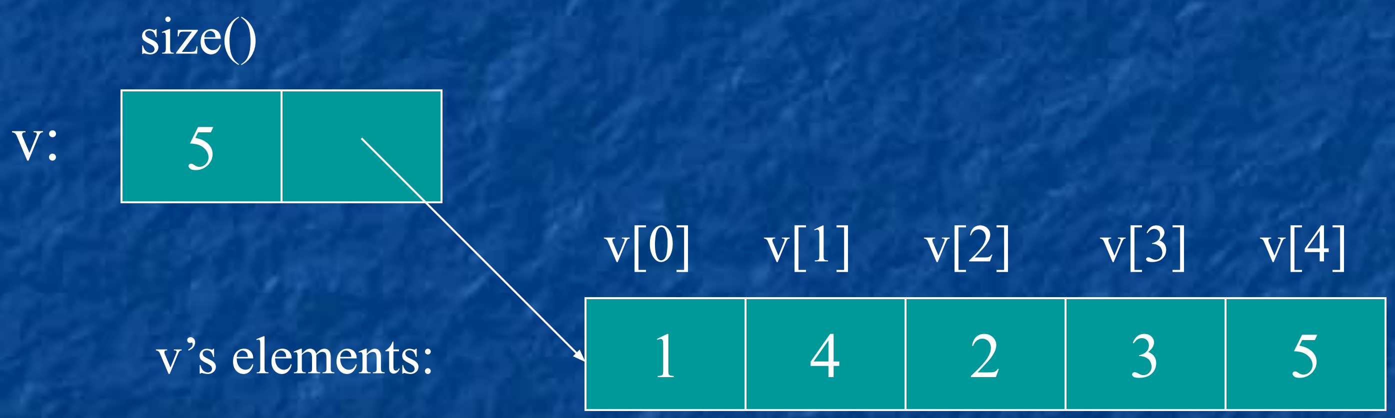
- To do just about anything of interest, we need a collection of data to work on. We can store this data in a **vector**. For example:

```
// read some temperatures into a vector:
int main()
{
    vector<double> temps;    // declare a vector of type double to store
                             // temperatures – like 62.4
    double temp;             // a variable for a single temperature value
    while (cin>>temp)        // cin reads a value and stores it in temp
        temps.push_back(temp);   // store the value of temp in the vector
    // ... do something ...
}
// cin>>temp  will return true until we reach the end of file or encounter
// something that isn't a double: like the word "end"
```

Vector

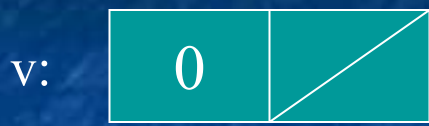
- Vector is the most useful standard library data type
  - a **vector<T>** holds an sequence of values of type **T**
  - Think of a vector this way

    A vector named **v** contains 5 elements: {1, 4, 2, 3, 5}:

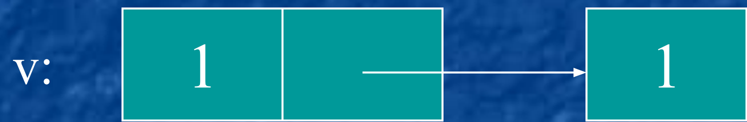


Vectors

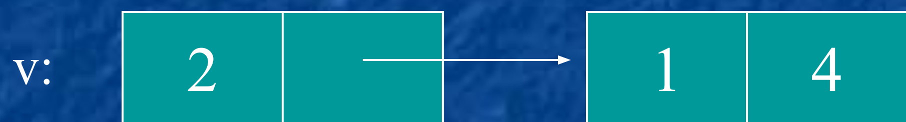
vector<int> v; // start off empty



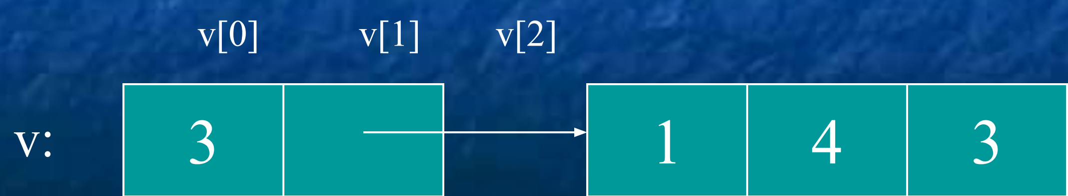
v.push_back(1); // add an element with the value **1**



v.push_back(4); // add an element with the value **4** at end ("the back")



v.push_back(3); // add an element with the value **3** at end ("the back")



Vectors

- Once you get your data into a vector you can easily manipulate it:

```
// compute mean (average) and median temperatures:
int main()
{
    vector<double> temps;       // temperatures in Fahrenheit, e.g. 64.6
    double temp;
    while (cin>>temp)  temps.push_back(temp); // read and put into vector

    double sum = 0;
    for (int i = 0; i< temps.size(); ++i) sum += temps[i];
                                // sums temperatures

    cout << "Mean temperature: " << sum/temps.size() << endl;
    sort(temps.begin(),temps.end());
    cout << "Median temperature: " << temps[temps.size()/2] << endl;
}
```

Combining Language Features

- You can write many new programs by combining language features, built-in types, and user-defined types in new and interesting ways.
  - So far, we have
    - Variables and literals of types **bool, char, int, double**
    - **vector, push_back(), [ ]** (subscripting)
    - **!=, ==, =, +, -, +=, <, &&, ||, !**
    - **max( ), sort( ), cin>>, cout<<**
    - **if, for, while**
  - You can write a lot of different programs with these language features! Let's try to use them in a slightly different way…

Example – Word List

```
// "boilerplate" left out

vector<string> words;
string s;
while (cin>>s && s != "quit")        // && means AND
  words.push_back(s);

sort(words.begin(), words.end());    // sort the words we read

for (int i=0; i<words.size(); ++i)
  cout<<words[i]<< "\n";

/*
    read a bunch of strings into a vector of strings, sort
    them into lexicographical order (alphabetical order),
    and print the strings from the vector to see what we have.
*/
```

Word list – Eliminate Duplicates

// Note that duplicate words were printed multiple times. For
// example "the the the". That's tedious, let's eliminate duplicates:

```
vector<string> words;
  string s;
  while (cin>>s && s!= "quit") words.push_back(s);

  sort(words.begin(), words.end());

  for (int i=1; i<words.size(); ++i)
    if(words[i-1]==words[i])
         "get rid of words[i]"     // (pseudocode)
  for (int i=0; i<words.size(); ++i) cout<<words[i]<< "\n";
```

// there are many ways to "get rid of words[i]"; many of them are messy
// (that's typical). Our job as programmers is to choose a simple clean
// solution – given constraints – time, run-time, memory.

Example (cont.) Eliminate Words!

```
// Eliminate the duplicate words by copying only unique words:
    vector<string> words;
    string s;
    while (cin>>s && s!= "quit")   words.push_back(s);
    sort(words.begin(), words.end());
    vector<string>w2;
    if (0<words.size()) {                  // Note style { }
      w2.push_back(words[0]);
      for (int i=1; i<words.size(); ++i)
            if(words[i-1]!=words[i])
                        w2.push_back(words[i]);
     }
    cout<< "found " << words.size()-w2.size() <<  " duplicates\n";
    for (int i=0; i<w2.size(); ++i)  cout << w2[i] << "\n";
```

Algorithm

- We just used a simple algorithm
- An algorithm is (from Google search)
  - "a logical arithmetical or computational procedure that, if correctly applied, ensures the solution of a problem." – *Harper Collins*
  - "a set of rules for solving a problem in a finite number of steps, as for finding the greatest common divisor." – *Random House*
  - "a detailed sequence of actions to perform or accomplish some task. Named after an Iranian mathematician, Al-Khawarizmi. Technically, an algorithm must reach a result after a finite number of steps, …The term is also used loosely for any sequence of actions (which may or may not terminate)." – *Webster's*
- We eliminated the duplicates by first sorting the vector (so that duplicates are adjacent), and then copying only strings that differ from their predecessor into another vector.

Ideal

- Basic language features and libraries should be usable in essentially arbitrary combinations.
  - We are not too far from that ideal.
  - If a combination of features and types make sense, it will probably work.
    - The compiler helps by rejecting some absurdities.

The next lecture

- How to deal with errors