LIX, École Polytechnique

Introduction to C++: Exercises

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Contents

Chapter 1

Generalities

1.1 Definition of *program*

(a) Your clothes are dirty and you want to put them in the washing machine. You put the temperature at 50 C° and set the cycle at "coloured cottons"; you satisfy yourself that you don't have a full load, so you press the "half-load" button; finally, you start the washing cycle. Is this a program? (b) Now suppose your girlfriend tells you to "do the washing, please". Is this a program? Justify your answers.

1.1.1 Solution

(a) The washing machine is a mechanical computer insofar as it does not interpret its instructions but simply executes them. The instructions for 50 C°, "coloured cottons", "half-load" and "start" are precisely defined by control knobs and button positions on the washing machines. Therefore the washing machine can correctly interpret the instructions given in the text. This means it is a program. (b) The object of the sentence "do the washing" has not been specified: the understanding rests upon the convention of the English language whereby "the washing" usually refers to washing clothes rather than anything else. In other words, interpretation of the sentence requires a human mind. Therefore, this is not a program.

1.2 Definition of *programming language*

Are the rules of chess a programming language? Justify your answer.

1.2.1 Solution

The game of chess has a well-defined set of rules according to which it can be played. Furthermore, these rules can be correctly interpreted by a computer. However, these rules only say how to form a valid move, but not which move to choose. In other words, the rules of chess do not supply a computer with the sequence of operations to follow in order to interpret them. Rather, they restrict the choice to a subset of all possible sequences of operations (moves) to perform. In this sense, the rules of chess do not form valid instructions. Therefore, they are not a programming language. Computers programs that play chess only use the rules of chess as a constraint on the possible moves, but they use much more complex algorithms to determine which move to make.

1.3 Indentation

Give a precise definition of the concept “well-indented C++ program”. Check whether your definition correctly classifies the following snippets of code. In the case of programs that are not well-indented, find the reason why they are not.

```
// 1. this is a well-indented C++ program
#include<iostream>
int main(int argc, char** argv) {
  int ret = 0;
  std::cout << "Hello world" << std::endl;
  return ret;
}

// 2. this is a well-indented C++ program
#include<iostream>
const int theGlobalValue = 0;
int main(int argc, char** argv) {
  theGlobalValue = 1;
  std::cout << theGlobalValue << std::endl;
  return 0;
}

// 3. this is NOT a well-indented C++ program (why?)
#include<iostream>
int main(int argc, char** argv) {
  if (argc < 2) {
    std::cerr << "error" << std::endl;
    } else {
      std::cout << argv[1] << std::endl;
  }
}

// 3. this is NOT a well-indented C++ program (why?)
#include<iostream>
  const int theGlobalValue = 0;
  bool isArgcGood(int argc) {
    if (argc < 2) {
      std::cout << "error" << std::endl;
      return false; }
    return true;
  }
  int main(int argc, char** argv) {
  if (isArgcGood(argc)) {
    std::cout << argv[1] << std::endl;
  }
  return 0;
}

// 4. this is NOT a well-indented C++ program (why?)
#include<iostream>
int main(int argc, char** argv) {
  int i = 0;
  while(argv[i]) i++;
  std::cout << i << std::endl;
}
```

1.3.1 Solution

Definition
A *C++ program* is a set of instructions of the C++ programming language that can be interpreted by a computer into a sequence of basic operations that the computer can perform.

Axiom
A C++ program consists of a set of global declarations/definitions and several nested groups of instructions. Each group of instructions is delimited by curly brackets ({ }).

Definition
The *rank* of a group of instructions in a C++ program is the nesting level of the group in the program. Global declarations/definitions are defined to be at rank 0.

Definition
Consider a C++ program with instructions $I_1, \ldots, I_n$. For a given $K > 0$, a group of t instructions $(I_h, \ldots, I_{h+t})$ at rank r in a C++ program is *well-K-indented* if:

1. no two instructions are on the same line of text;
2. the opening curly bracket is on a line of text above I_h and the closing curly bracket is on a line of text below I_{h+t};
3. I_{h-1} (the last instruction at rank $r-1$ before the beginning of the group) starts K columns of text before I_h;
4. the closing curly brace of the group is aligned with instruction I_{h-1} (in other words, it is positioned K columns of text before I_{h+t}).

Definition
A C++ program is *well-indented* if there is an integer $K > 0$ such that (a) the global declarations/definitions start at column 0, and (b) each of its instruction groups is well-K-indented.

Fact
Usual values for K are 2, 4, 8. In this course, the value $K = 2$ is favoured as it allows for a greater number of nesting levels to be displayed in 80 characters (the usual screen width on UNIX systems).

Chapter 2

Basic syntax

2.1 A minimal C++ program

Edit, save and build the following program.

```
/***********************************************
* Name:       minimal.cxx
* Author:     Leo Liberti
* Source:     GNU C++
* Purpose:    minimal C++ program
* Build:      c++ -o minimal minimal.cxx
* History:    060818 work started
***********************************************/

#include<iostream>

int main(int argc, char** argv) {
  using namespace std;
  int ret = 0;

  // your code goes here

  return ret;
}
```

Now modify it to print the array of characters `argv[0]`.

2.1.1 Solution

Insert the statement `cout << argv[0] << endl;` before the `return ret;` statement.

2.2 Variables and pointers

Consider the following program.

```
#include<iostream>

const char endOfCharArray = '\0';

int main(int argc, char** argv) {
  using namespace std;
  int ret = 0;
  if (argc < 2) {
    cerr << "error: no arguments on cmd line" << endl;
    ret = 1;
  } else {
    for(int i = 0; i < argc; i++) {
      while(*(argv[i]) != endOfCharArray) {
        cout << *(argv[i]);
        argv[i]++;
      }
      cout << endl;
    }
  }
  return ret;
}
```

(a) List the variables in the program and their types. (b) List the pointers in the program and their types. (c) How many pointers are there in the program when it is run with the command line `./variables_pointers 123 456 789`? (d) Edit, save, build and run the program with the command line above. What is the output?

2.2.1 Solution

(a) `char endOfCharArray`, `int argc`, `char** argv`, `int ret`, `int i`. (b) `char** argv`, `char* argv[`i`]` for all $i \in \{0, \dots, \texttt{argc} - 1\}$. (c) Five pointers: `argv` and `argv[`i`]` with $0 \le i \le 3$. (d) The output is:

```
./variables_pointers
123
456
789
```

2.3 The second word

(a) Write a program that writes the second word (and its length) in an array of characters. Words are separated by spaces, punctuation and tabs. Test your code on the sentence "Actually, couldn't you come with me?" The correct answer should be `couldn't(8)`. If you're stuck, you can follow the template below.

```
// test if c is in the array containing all the valid separators
bool isSeparator(char c, char* separators);
// return the length of the char array a
int charArrayLength(char *a);
int main(int argc, char** argv) {
  // find the beginning of the second word
  // find the end of the second word
}
```

2.3.1 Solution

```
/***********************************************
* Name:       secondword.cxx
* Author:     Leo Liberti
* Source:     GNU C++
* Purpose:    minimal C++ program
* Build:      c++ -o secondword secondword.cxx
* History:    060818 work started
***********************************************/

#include<iostream>

bool isSeparator(char c, char* separators) {
  char endOfString = '\0';
  char* sepPtr = separators;
  bool ret = false;
  while(*sepPtr != endOfString) {
    if (c == *sepPtr) {
      ret = true;
      break;
    }
    sepPtr++;
  }
  return ret;
}

int charArrayLength(char* a) {
  int ret = 0;
  char endOfString = '\0';
  while(*a != endOfString) {
    ret++;
    a++;
  }
  return ret;
}

int main(int argc, char** argv) {
  using namespace std;
  int ret = 0;

  char endOfString = '\0';
  char theSentence[] = "Actually, couldn't you come with me?";
  char separators[] = " \t,.;:?!";
  char* strPtr = theSentence;
  char* strEnd;

  // find the beginning of the second word
  bool isSecondWord = false;
  while(*strPtr != endOfString) {
    while(isSeparator(*strPtr, separators)) {
      // while deals with case with consecutive separators
      strPtr++;
      isSecondWord = true;
    }
    if (isSecondWord) {
      // end of consecutive separators, means second word starts at strPtr
      break;
    } else {
      // character was not a separator, continue
      strPtr++;
    }
  }

  // find the end of the second word
  strEnd = strPtr;
  while(*strEnd != endOfString) {
    if (isSeparator(*strEnd, separators)) {
      // first separator found after second word, mark the end
      *strEnd = endOfString;
      break;
    }
    strEnd++;
  }

  // print the second word and its length
  cout << strPtr << "(" << charArrayLength(strPtr) << ")" << endl;

  return ret;
}
```

2.4 Random numbers

The following code can be used to generate pseudo-random floating point numbers in $[0, 1]$.

```
#include<iostream>
#include<sys/time.h>

int main(int argc, char** argv) {
  using namespace std;

  // initialize randomizer
  struct timeval theTV;
  struct timezone theTZ;
  gettimeofday(&theTV, &theTZ);
  srandom(theTV.tv_usec);

  // pick a random number between 0 and 1
  double normalizedRndCoeff = (double) random() / (double) RAND_MAX;
  cout << normalizedRndCoeff << endl;
  return 0;
}
```

Write a small program that generates a random sample of given size N (input from command line) and that computes the mean and the variance. Use your program to show empirically that

$$\alpha = \lim_{N\to\infty} \mathrm{Var}(X) \cong 0.083,$$

where X is a random variable. Prove that $\alpha = \frac{1}{12}$.

Optional: update your program to generate a random sample whose elements are within given numerical bounds.

2.4.1 Solution

```
#include<iostream>
#include<cstdlib>
#include<cmath>
#include<sys/time.h>

int main(int argc, char** argv) {
  using namespace std;

  // read sample size from command line
  if (argc < 2) {
    cerr << "meanvariance: sample size needed on command line" << endl;
    return 1;
  }
  int sampleSize = atoi(argv[1]);
  if (sampleSize <= 0) {
    cerr << "meanvariance: sample size must be strictly positive" << endl;
    return 2;
  }

  // initialize randomizer
  struct timeval theTV;
  struct timezone theTZ;
  gettimeofday(&theTV, &theTZ);
  srandom(theTV.tv_usec);

  // generate the sample (numbers between 0 and 1)
  double* sample = new double[sampleSize];
  for(int i = 0; i < sampleSize; i++) {
    sample[i] = (double) random() / (double) RAND_MAX;
  }

  // compute the mean
  double mean = 0;
  for(int i = 0; i < sampleSize; i++) {
    mean += sample[i];
  }
  mean /= (double) sampleSize;

  // compute the variance
  double variance = 0;
  double dtmp = 0;
  for(int i = 0; i < sampleSize; i++) {
    dtmp = sample[i] - mean;
    dtmp *= dtmp;
    variance += dtmp;
  }
  variance /= (double) sampleSize;

  // compute the standard deviation
  double stddev = sqrt(variance);

  // output
  cout << "mean = " << mean << "; variance = " << variance
       << "; std deviation = " << stddev << endl;

  delete [] sample;
  return 0;
}
```

Let $x = (x_1, \ldots, x_N)$ a sample of size N of values of the random variable X.

$$\mathrm{Var}(X) = \int_0^1 x^2 - \frac{1}{4} = \frac{1}{12}$$

Chapter 3

Classes

3.1 Complex numbers

The following code is the class header describing a complex number class.

```
/*
** Name:     complex.h
** Author:   Leo Liberti
** Purpose:  header file for a complex numbers class
** Source:   GNU C++
** History:  061019 work started
*/

#ifndef _COMPLEXH
#define _COMPLEXH

#include<string>
#include<iostream>

class Complex {

 public:

  Complex();
  Complex(double re, double im);
  ~Complex();

  double getReal(void);
  double getImaginary(void);
  void setReal(double re);
  void setImaginary(double im);
  void fromString(const std::string& complexString);

  Complex operator+(Complex& theComplex);
  Complex operator-(Complex& theComplex);
  Complex operator*(Complex& theComplex);
  Complex operator/(Complex& theComplex);

 private:
  double real;
  double imag;
};

std::ostream& operator<<(std::ostream& out, Complex& theComplex);

#endif
```

Write the corresponding implementation file `complex.cxx`. Test it on the following `main()` function definition, using the command `./test 2.1+0.2i / 0.2-0.3i`. The output should be `2.76923 + 5.15385i`.

```
/*
```

```
** Name:     test.cxx
** Author:   Leo Liberti
** Purpose:  testing the complex numbers class
** Source:   GNU C++
** History:  061019 work started
*/

#include <iostream>
#include <string>
#include "complex.h"

int main(int argc, char** argv) {
  using namespace std;
  if (argc < 4) {
    cerr << "need an operation on command line" << endl;
    cerr << "   e.g. ./test 4.3+3i - 2+3.1i" << endl;
    cerr << "   (no spaces within each complex number, use spaces to\n";
    cerr << "    separate the operands and the operator - use arithmetic\n";
    cerr << "    operators only)" << endl;
    return 1;
  }
  string complexString1 = argv[1];
  string complexString2 = argv[3];
  Complex complex1;
  complex1.fromString(complexString1);

  Complex complex2;
  complex2.fromString(complexString2);

  Complex complex3;
  if (argv[2][0] == '+') {
    complex3 = complex1 + complex2;
  } else if (argv[2][0] == '-') {
    complex3 = complex1 - complex2;
  } else if (argv[2][0] == '*' || argv[2][0] == '.') {
    argv[2][0] = '*';
    complex3 = complex1 * complex2;
  } else if (argv[2][0] == '/') {
    complex3 = complex1 / complex2;
  }
  cout << complex1 << " " << argv[2][0] << " (" << complex2 << ") = "
       << complex3 << endl;
  return 0;
}
```

Use the following `Makefile` to compile (use tabs, not spaces after each label — for that you need to use the Emacs editor):

```
# Name:     complex.Makefile
# Author:   Leo Liberti
# Purpose:  makefile for complex class project
# Source:   GNU C++
# History:  061019 work started

CXXFLAGS = -g

all: test

test: complex.o test.cxx
	c++ $(CXXFLAGS) -o test test.cxx complex.o

complex.o: complex.cxx complex.h
	c++ $(CXXFLAGS) -c -o complex.o complex.cxx

clean:
	rm -f *~ complex.o test
```

3.1.1 Solution

```
/*
** Name:     complex.cxx
** Author:   Leo Liberti
** Purpose:  implementation of a complex numbers class
** Source:   GNU C++
** History:  061019 work started
```

```
*/

#include<iostream>
#include<string>
#include<sstream>
#include<cstdlib>
#include<cmath>
#include "complex.h"

const char charPlusOp = '+';
const char charMinusOp = '-';
const char charIValue = 'i';

Complex::Complex() : real(0.0), imag(0.0) { }

Complex::Complex(double re, double im) : real(re), imag(im) { }

Complex::~Complex() { }

double Complex::getReal(void) {
  return real;
}

double Complex::getImaginary(void) {
  return imag;
}

void Complex::setReal(double re) {
  real = re;
}

void Complex::setImaginary(double im) {
  imag = im;
}

void Complex::fromString(const std::string& complexString) {
  using namespace std;
  string realString;
  string imagString;
  stringstream stringBufReal;
  stringstream stringBufImag;
  int opPos = complexString.find(charPlusOp);
  int iPos;
  if (opPos != complexString.npos) {
    // deal with cases re + im i
    realString = complexString.substr(0, opPos);
    stringBufReal.str(realString);
    stringBufReal >> real;
    imagString = complexString.substr(opPos + 1);
    stringBufImag.str(imagString);
    stringBufImag >> imag;
    if (imag == 0) {
      // case re + i
      imag = 1;
    }
  } else {
    opPos = complexString.find(charMinusOp);
    if (opPos != complexString.npos && opPos > 0) {
      // deal with cases re - im i
      realString = complexString.substr(0, opPos);
      stringBufReal.str(realString);
      stringBufReal >> real;
      imagString = complexString.substr(opPos + 1);
      stringBufImag.str(imagString);
      stringBufImag >> imag;
      if (imag == 0) {
// case re - i
imag = 1;
      }
      imag = -imag;
    } else {
      opPos = complexString.find(charIValue);
      if (opPos != complexString.npos) {
// deal with case im i
imagString = complexString.substr(0, opPos);
stringBufImag.str(imagString);
stringBufImag >> imag;
      } else {
// deal with case re
stringBufReal.str(complexString);
stringBufReal >> real;
```

```
      }
    }
  }
}

Complex Complex::operator+(Complex& theComplex) {
  return Complex(real+ theComplex.getReal(), imag + theComplex.getImaginary());
}

Complex Complex::operator-(Complex& theComplex) {
  return Complex(real- theComplex.getReal(), imag - theComplex.getImaginary());
}

Complex Complex::operator*(Complex& theComplex) {
  double re = real * theComplex.getReal() - imag * theComplex.getImaginary();
  double im = imag * theComplex.getReal() + real * theComplex.getImaginary();
  return Complex(re, im);
}

Complex Complex::operator/(Complex& theComplex) {
  double c = theComplex.getReal();
  double d = theComplex.getImaginary();
  double denom = c*c + d*d;
  double re;
  double im;
  if (denom == 0) {
    re = 1e100;
    im = 1e100;
  }
  re = (real*c + imag*d) / denom;
  im = (imag*c - real*d) / denom;
  return Complex(re, im);
}

std::ostream& operator<<(std::ostream& out, Complex& theComplex) {
  using namespace std;
  double re = theComplex.getReal();
  double im = theComplex.getImaginary();
  if (im > 0 && re != 0) {
    if (im != 1) {
      out << re << " + " << im << "i";
    } else {
      out << re << " + i";
    }
  } else if (im < 0 && re != 0) {
    if (im != -1) {
      out << re << " - " << fabs(im) << "i";
    } else {
      out << re << " - i";
    }
  } else if (re == 0) {
    out << im << "i";
  } else if (im == 0) {
    out << re;
  }
  return out;
}
```

3.2 Virtual inheritance

The code below defines a virtual base class `VirtualBase` and a derived class `Derived` which implements it. The `VirtualBase` interface is simply to set and get an integer value. The `Derived` adds a method for printing the value. We then have two functions in the global namespace, `printTheValue1()` and `printTheValue2()`, which print out the values in different ways: the first simply uses the get method of the interface to retrieve the value; the second tries to transform the `VirtualBase` interface pointer passed as argument to a pointer to the `Derived` class, and then calls the `Derived` class' print method.

```
// this program does not compile!
#include<iostream>
```

```
class VirtualBase {
public:
  virtual ~VirtualBase() { }
  virtual void setValue(int i) = 0;
  virtual int getValue(void) = 0;
};

class Derived : public virtual VirtualBase {
public:
  ~Derived() { }
  void setValue(int i) {
    theValue = i;
  }
  int getValue(void) {
    return theValue;
  }
  void printValue(void) {
    std::cout << "Derived::printValue(): value is " << theValue << std::endl;
  }
private:
  int theValue;
};

void printTheValue1(VirtualBase* v) {
  std::cout << "printTheValue1(): value is " << v->getValue() << std::endl;
}

void printTheValue2(VirtualBase* v) {
  Derived* d = v;
  d->printValue();
}

int main(int argc, char** argv) {
  int ret = 0;
  Derived d;
  VirtualBase* v = &d;
  v->setValue(1);
  printTheValue1(v);
  printTheValue2(v);
  return ret;
}
```

The desired output is:

```
printTheValue1(): value is 1
Derived::printValue(): value is 1
```

However, the program fails to compile with the error:

```
virtual2.cxx: In function 'void printTheValue2(VirtualBase*)':
virtual2.cxx:31: error: invalid conversion from 'VirtualBase*' to 'Derived*'
```

```
virtual2.cxx:31: error: cannot convert from base 'VirtualBase'
                 to derived type 'Derived' via virtual base 'VirtualBase'
```

What has gone wrong? How can you fix this program? [**Hint**: look at C++ casting operators]

3.2.1 Solution

The problem on line 31 `Derived* d = v;` is given by the fact that we are attempting to cast a pure virtual base class into a derived class at compile-time: this is not possible. Instead, we have to employ the `dynamic_cast` operator and replace line 31 with:

```
  Derived* d = dynamic_cast<Derived*>(v);
```

This fixes the problem.

3.3 Virtual and nonvirtual inheritance

What is the output of the following code?

```
#include<iostream>

class A {
public:
  void f() {
    std::cout << "A::f" << std::endl;
  }
  virtual void g() {
    std::cout << "A::g" << std::endl;
  }
};

class B : public A {
public:
  void f() {
    std::cout << "B::f" << std::endl;
  }
  virtual void g() {
    std::cout << "B::g" << std::endl;
  }
};

int main(int argc, char** argv) {
  A a;
  B b;
  A* aPtr = &a;
  A* bPtr = &b;
  aPtr->f();
  aPtr->g();
  bPtr->f();
  bPtr->g();
  return 0;
}
```

Is there anything surprising? Can you explain it?

3.3.1 Solution

The output is

```
A::f
A::g
A::f
B::g
```

Since this is produced by this code:

```
aPtr->f();
aPtr->g();
bPtr->f();
bPtr->g();
```

It is surprising that the pointer to the `B` object does not print `B::f` but `A::f`. The reason is that the derived class `B` hides the method `A::f()`, which was *not* declared virtual. This is known as *compile-time polymorphism*: at compile-time, the compiler only knows that `bPtr` is of type `A*`, and therefore binds to it the `f()` method found in `A`. The `g()` method, however, was declared `virtual` in the base class, which means that the compiler will implement *run-time polymorphism* (almost always the desired kind), and will delegate binding decisions (i.e. , deciding what method to call) to run-time. At run-time, even though `bPtr` is of type `A*`, it is possible to find out that in fact it points to an object of type `B`, so the correct binding takes place.

3.4 Nonvirtual base class destructor

The code below shows the ill effects of hiding a non-virtual constructor of a base class, and then using the derived class as a base one.

```
// this program is buggy!
#include<iostream>

class Base {
public:
  Base() {
    std::cerr << "constructing Base " << this << std::endl;
    i = new int;
  }
  ~Base() {
    std::cerr << "destroying Base " << this << std::endl;
    delete i;
  }
private:
  int* i;
};

class Derived : public Base {
public:
  Derived() {
    std::cerr << "constructing Derived " << this << std::endl;
    d = new double;
  }
  ~Derived() {
    std::cerr << "destroying Derived " << this << std::endl;
    delete d;
  }
private:
  double* d;
};

int main(int argc, char** argv) {
  using namespace std;
  int ret = 1;
  Base* thePtr = new Derived;
  delete thePtr;
  return ret;
}
```

The output of this program is

```
constructing Base 0x804a008
constructing Derived 0x804a008
destroying Base 0x804a008
```

This is a bug, because the `Derived` object was never deallocated. At best, this is a memory leak. In some other cases it may become the source of more serious problems. Can you explain what happened and how to fix the program?

3.4.1 Solution

The main code allocates a `Derived` object on the heap but uses a `Base` pointer to store its address, exploiting polymorphism. Since the destructor is not declared virtual, the binding occurs at compile-time: since `thePtr` is of type `Base*`, the destructor called is the one for the `Base` class even though `thePtr` actually points to an object of type `Derived`.

As is said in the "C++ Gotchas" book by S. Dewhurst (gotcha #70), this bug causes unpredictable behaviour.

> *Chances are you'll just get a call of the base class destructor for the derived class object: a bug. But the compiler may decide to do anything else it feels like (dump core? send nasty email to your boss? sign you up for a lifetime subscription to "This week in Object-Oriented COBOL"?).*

Chapter 4

Debugging

4.1 Segmentation fault

The following code contains three serious memory bugs, usually ending in a segmentation fault. Find the bugs, solve them and explain them.

```
// this program is buggy
#include<iostream>
int main(int argc, char** argv) {
  using namespace std;
  double* d = new double;
  for(unsigned int i = 0; i < 3; i++) {
    d[i] = 1.5 + i;
  }
  for(unsigned int i = 2; i >= 0; i--) {
    cout << d[i] << endl;
  }
}
```

4.1.1 Solution

If we just compile and run the program, we obtain a lot of output, structured more or less as follows:

```
3.5
2.5
1.5
3.60739e-313
0
[...]
0
3.66616e-307
5.09279e-313
nan
nan
```

```
[...]
Segmentation fault
```

This is usually known as `garbage output`. The first three lines are the expected output, but we fail to understand why did the program not stop on the second loop when it was told. Furthermore, why the `Segmentation fault`?

We build the program with the debugging flag set `c++ -g -o segmentationfault segmentationfault.cxx` and then debug it using `valgrind`: `valgrind -q ./segmentationfault`. We obtain the usual garbage interspersed with meaningful `valgrind` messages. We can run it again saving the standard error stream to the standard output and redirecting it through a pager: `valgrind -q ./segmentationfault 2¿&1 — less`. `valgrind`'s messages are:

```
==31179== Invalid write of size 8
==31179==    at 0x8048681: main (segmentationfault.cxx:6)
==31179==  Address 0x426A030 is 0 bytes after a block of size 8 alloc'd
==31179==    at 0x401A878: operator new(unsigned) (vg_replace_malloc.c:163)
==31179==    by 0x804864D: main (segmentationfault.cxx:4)
==31179==
==31179== Invalid read of size 4
==31179==    at 0x804869E: main (segmentationfault.cxx:9)
==31179==  Address 0x426A03C is 12 bytes after a block of size 8 alloc'd
==31179==    at 0x401A878: operator new(unsigned) (vg_replace_malloc.c:163)
==31179==    by 0x804864D: main (segmentationfault.cxx:4)
==31179==
==31179== Invalid read of size 4
==31179==    at 0x80486A1: main (segmentationfault.cxx:9)
==31179==  Address 0x426A038 is 8 bytes after a block of size 8 alloc'd
==31179==    at 0x401A878: operator new(unsigned) (vg_replace_malloc.c:163)
==31179==    by 0x804864D: main (segmentationfault.cxx:4)
==31179==
==31179== Process terminating with default action of signal 11 (SIGSEGV)
==31179==  Bad permissions for mapped region at address 0x4262FFC
==31179==    at 0x804869E: main (segmentationfault.cxx:9)
```

The first error, `Invalid write`, is very serious. It means we are writing on heap memory we had not allocated. This usually results immediately in unpredictable behaviour and the fatal segmentation fault error. We can find out at which step of the loop the error arises by inserting a print statement `cout << "*** " << i << endl;` before line 6, rebuilding, and running `valgrind` again. We see immediately that the `Invalid write` occurs when `i` has value 1. It is important to remove the temporary print statement in order to keep the line numbers valid. The fact that `d[0]` exists in memory but `d[1]` is invalid should immediately tell us that we failed to allocate enough memory. In particular, we issued the C++ statement `double* d = new double;`, which reserves space on the heap for just one double floating point number. What we really wanted to do, in fact, was to have space for an array of size 3: `double* d = new double[3];`.

We now rebuild and re-run the program. Again we get garbage output. `valgrind` reveals that the first error has been fixed:

```
==31348== Invalid read of size 4
==31348==    at 0x804869E: main (segmentationfault.cxx:9)
==31348==  Address 0x426A024 is 4 bytes before a block of size 24 alloc'd
==31348==    at 0x401ACE0: operator new[](unsigned) (vg_replace_malloc.c:195)
```

```
==31348==    by 0x804864D: main (segmentationfault.cxx:4)
==31348==
==31348== Invalid read of size 4
==31348==    at 0x80486A1: main (segmentationfault.cxx:9)
==31348==  Address 0x426A020 is 8 bytes before a block of size 24 alloc'd
==31348==    at 0x401ACE0: operator new[](unsigned) (vg_replace_malloc.c:195)
==31348==    by 0x804864D: main (segmentationfault.cxx:4)
==31348==
==31348== Process terminating with default action of signal 11 (SIGSEGV)
==31348==  Bad permissions for mapped region at address 0x4262FFC
==31348==    at 0x804869E: main (segmentationfault.cxx:9)
```

The `Invalid read` error is not as serious as the `Invalid write`, but almost as bad. It means that we are reading from unallocated memory.

To see what is happening we launch `ddd` and we set a breakpoint at line 9 `break segmentationfault.cxx:9`. Then we start debugging `run`. Since the problem is that the loop does not seem to terminate as it should, we want to keep track of the counter `i`. With `display i` we can have `i`'s value printed after each step `next`. After a few steps, we find that `i` has value 0. Instead of terminating, the loop continues with `i` set at 4294967295. Naturally, the condition `i >= 0` is still verified so that's the reason why the loop continues. The strange value in `i` is due to the fact that the counter was declared `unsigned int`, which means that it can never take negative values — in other words, 0 is the minimum value that `i` can take. When an `unsigned int` is set at 0 (as `i` in our case) and then a decrement operator is applied to it (`i--` within the `for` statement), it is set to "one less than the minimum value", which by definition is taken to be the *maximum* value (i.e. a large, positive value). Thus the bug is explained. It can be fixed by taking away the `unsigned` qualifier.

We rebuild, re-run the program and find that it works without any trouble whatsoever:

```
3.5
2.5
1.5
```

The third bug is much harder to find, since the behaviour of the program is now correct. We can identify it by enclosing the whole program into an endless loop:

```
int main(int argc, char** argv) {
  using namespace std;
  while(true) {
    double* d = new double[3];
    for(int i = 0; i < 3; i++) {
      d[i] = 1.5 + i;
    }
    for(int i = 2; i >= 0; i--) {
      cout << d[i] << endl;
    }
  }
}
```

We now build and run the program, and in another shell we launch the shell command `top -d 1`. In the last column of this window we find some program names which are running on the computer. We find the line relative to `segmentationfault`:

```
31467 liberti   25   0  9044 7404  764 R 18.9  1.2   0:04.85 segmentationfau
```

If we let our program run for a few seconds (minutes) we notice that on the column marked `%MEM` the percentage of memory dedicated to `segmentationfault` always increases. If we let this program run for a long time, it gobbles up the whole computer memory. On certain operating systems, this amounts to freezing the computer dead. On others, the process is automatically killed. In any case, we do not want any program of ours to follow this behaviour, called *memory leak*. It is easy to find that the cause of this bug is that we forgot to deallocate memory after the allocation. We insert the line `delete [] d;` right before the end of the program to fix this bug.

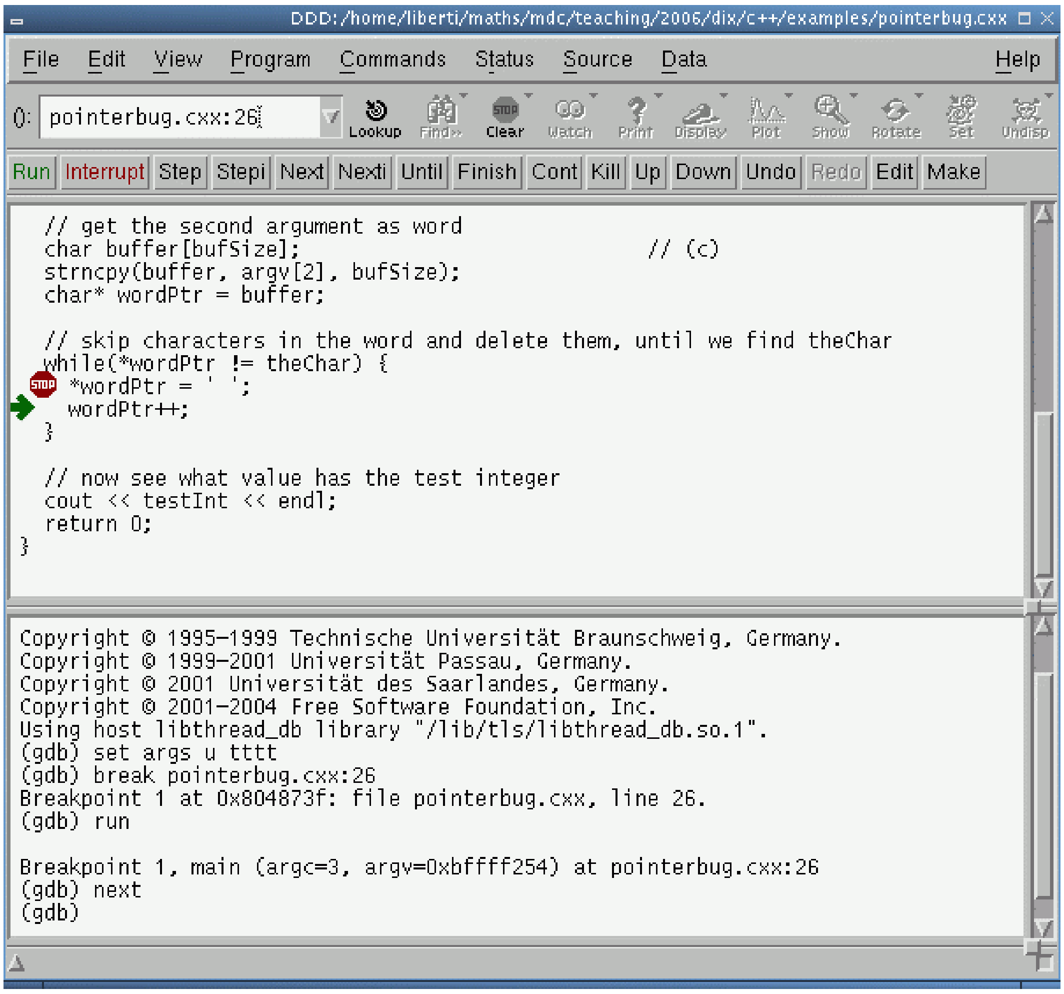
4.2 Pointer bug

The following snippet of code behaves unpredictably: it will often print a value for `testInt` which is different from 1, although in the variable `testInt` is never explicitly changed. Debug the program using `ddd` and `valgrind`. What is the bug? How can you fix it? Change the order of the statements marked (a), (b), (c) and test the resulting programs: what is the behaviour? Can you explain it?

```
// this program is buggy!
#include<iostream>
#include<cstring>

const int bufSize = 20;

int main(int argc, char** argv) {
  using namespace std;
  if (argc < 3) {
    cerr << "need a char and a word as arguments on cmd line" << endl;
    return 1;
  }

  // a test integer to which we assign the value 1
  int testInt = 1;                                    // (a)

  // get the first char of the first argument
  char theChar = argv[1][0];                          // (b)

  // get the second argument as word
  char buffer[bufSize];                               // (c)
  strncpy(buffer, argv[2], bufSize);
  char* wordPtr = buffer;

  // skip characters in the word and delete them, until we find theChar
  while(*wordPtr != theChar) {
    *wordPtr = ' ';
    wordPtr++;
    cout << (int) (wordPtr - buffer) << endl;
  }

  // now see what value has the test integer
  cout << testInt << endl;
  return 0;
}
```

4.2.1 Solution

First, we compile `pointerbug.cxx` using the debug `-g` option: `c++ -g -o pointerbug pointerbug.cxx`. To debug with `ddd`, we run: `ddd pointerbug`. We set command line arguments `e test` `set args e test` and set a breakpoint inside the `while` loop `break pointerbug.cxx:26`. We start the debugging session `run` which stops at the required breakpoint, on the line `*wordPtr = ' ';`. Putting the mouse pointer on the symbol `wordPtr` reveals on the window status line that the array pointed at by `wordPtr` is `"test"`. From here on, we debug one statement at a time by repeatedly issuing the command `next`. See Fig. 4.1.


DDD:/home/liberti/maths/mdc/teaching/2006/dix/c++/examples/pointerbug.cxx
File Edit View Program Commands Status Source Data Help
(): pointerbug.cxx:26
Lookup Find» Clear Watch Print Display Plot Show Rotate Set Undisp
Run Interrupt Step Stepi Next Nexti Until Finish Cont Kill Up Down Undo Redo Edit Make

```
  // get the second argument as word
  char buffer[bufSize];                          // (c)
  strncpy(buffer, argv[2], bufSize);
  char* wordPtr = buffer;

  // skip characters in the word and delete them, until we find theChar
  while(*wordPtr != theChar) {
    *wordPtr = ' ';
    wordPtr++;
  }

  // now see what value has the test integer
  cout << testInt << endl;
  return 0;
}
```

```
Copyright © 1995-1999 Technische Universität Braunschweig, Germany.
Copyright © 1999-2001 Universität Passau, Germany.
Copyright © 2001 Universität des Saarlandes, Germany.
Copyright © 2001-2004 Free Software Foundation, Inc.
Using host libthread_db library "/lib/tls/libthread_db.so.1".
(gdb) set args u tttt
(gdb) break pointerbug.cxx:26
Breakpoint 1 at 0x804873f: file pointerbug.cxx, line 26.
(gdb) run

Breakpoint 1, main (argc=3, argv=0xbffff254) at pointerbug.cxx:26
(gdb) next
(gdb)
```

Figure 4.1: The `ddd` frontend to the `gdb` debugger.

At line 27, the array has become `" est"` because the `'t'` character has been replaced by a space (this is the effect of line 26). A `next` command later, we are on line 25 (the `while` test). As `theChar` is equal to `'e'` and `*wordPtr` is also `'e'`, the test fails and the loop is exited. Three more `next` commands exit the debugging session without detecting any problem. We now change the command line arguments: `set args y test` and re-debug the program. We notice that, as the array pointed at by `wordPtr`, namely `"test"`, does not contain the `'y'` character, the `while` condition does not fail before the end of the array. It is not difficult to imagine that as the loop is repeated, characters in memory after the `wordPtr` array are set to contain spaces (as per line 26), so that eventually the whole memory adjacent to `wordPtr` is erased. As the variables are stored from the stack, the memory "after" the `wordPtr` array contains the values of the variables declared *before* the `wordPtr` array, namely the `testInt` variable. This is the reason why the program behaves incorrectly and unpredictably. This type of bug is a memory bug known as *stack corruption*, and it was engendered by the *array bound overflow* of the `wordPtr` pointer being increased past its legal limit.

The `valgrind` command-line debugging tool is usually very helpful in tracing memory bugs; in this case, however, its output is somewhat obscure. Running `valgrind -q ./pointerbug y test` yields

```
==28373== Conditional jump or move depends on uninitialised value(s)
==28373==    at 0x8048752: main (pointerbug.cxx:25)
538976288
```

Line 25 is the `while` condition. What `valgrind` is telling us is that at a certain point of the program execution, the test `(*wordPtr != theChar)` occurs over an uninitialised portion of memory. Now, `theChar` is certainly initialised (line 17), so this leaves the `*wordPtr` as the sole possible source of the problem. We can shed further light on this matter by printing a loop counter (so we know when the problem occurs). We do this by inserting the C++ line `cout << (int) (wordPtr - buffer) << endl;` after line 27. The output is now,

```
1
[...]
21
22
23
24
==28407== Conditional jump or move depends on uninitialised value(s)
==28407==    at 0x8048783: main (pointerbug.cxx:25)
25
26
27
538976288
```

At this point we immediately realize that the loop is counting past the end of string, as our given string `test` is only 4 characters long, and the program stops well past it. It is also interesting to notice that the first 25 bytes after `buffer` are all initialised parts of the stack: this is consistent with `buffer` being 20 bytes long (i.e. the vale of `bufSize`), `theChar` occupying only 1 byte of memory, and `testInt` being a 32 bit (i.e. 4 bytes) integer of type `int`.

One further point of interest is, why should the program terminate at all? Supposing there is no `'y'` character in the memory starting from `buffer`, the `while` condition would never be satisfied. This is indeed the case, but the fact is that the overall distribution of byte values in memory is close to uniform, so that it is likely that each ASCII value from 0 to 255 will eventually be found in such a large chunk of memory.

In order to fix the bug, it suffices change the `while` condition to

```
(*wordPtr != theChar && *wordPtr != '\0' && (int) (wordPtr - buffer) < bufSize)
```

so that the end-of-char-array delimiter (the `NULL` byte), as well as the maximum array size checking condition may also be able to stop the loop.

To answer the last part of the question, the value 1 contained in `testInt` will not be affected by the bug described above if `testInt` is declared after `buffer`, because the statement `*wordPtr = ' ';` will then overwrite memory after `buffer` (which, because the variables are on the stack, refers to variables declared *before* `buffer`).

4.3 Scope of local variables

Inspect the following code. Convince yourself that the expected output should be `0 1 2 3 4`. Compile and test the code. The output is unpredictable (may be similar to `134524936 134524968 134524952 134524984 134525024` depending on the machine and circumstances). How do you explain this bug? How can you fix it?

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

class ValueContainer {
public:
  ValueContainer() : theInt(0) { }
  ~ValueContainer() { }
  void set(int* t) {
    theInt = t;
  }
  int get(void) {
    return *theInt;
  }
private:
  int* theInt;
};

ValueContainer* createContainer(int i) {
  ValueContainer* ret = new ValueContainer;
  ret->set(&i);
  return ret;
}

const int vecSize = 5;
int main(int argc, char** argv) {
  using namespace std;
  vector<ValueContainer*> value;
  for(int i = 0; i < vecSize; i++) {
    value.push_back(createContainer(i));
  }
  for(int i = 0; i < vecSize; i++) {
    cout << value[i]->get() << " ";
  }
  cout << endl;
  for(int i = 0; i < vecSize; i++) {
    delete value[i];
  }
  return 0;
}
```

4.3.1 Solution

The `ValueContainer::myInt` pointer is always initialized to the address of a local variable, namely the `i` passed to the `createContainer(int)` method. Local variables are allocated on the stack and are deallocated as soon as their scope is closed. In this case, the `i` variable local to `createContainer` is deallocated at the end of the `createContainer` method, hence the pointer which has been stored in the `ret` pointer to `ValueContainer` object points to an unused area of the stack. Chances are this stack area will be overwritten when functions are called and returned from, so the output is unpredictable.

There are several ways to fix this bug. The most direct is to replace the statement `ret->set(&i);` with `ret->set(new int(i));`, and to add the statement `delete theInt;` in the class destructor.

A more meaningful bugfix would involve recognizing that the semantics of the class is wrong. Set/get pairs should behave with the same data, and the fact that the integer data within the class (`theInt`) has a name which does not remind of a pointer are strong hints that the real bug was to design a class that stores an integer pointer when all that was needed was simply an integer. Thus the "correct correction" is to make all changes so that `theInt` is an *integer variable* instead of a pointer to integer.

4.4 Erasing elements from a vector

The following code initializes an STL vector of integers to $(2, 1)$ then iterates to erase all elements with value 1. The code compiles but on running it we get a segmentation fault abort. Find and fix the bug.

```
// this program is buggy!
#include<vector>
int main(int argc, char** argv) {
  using namespace std;
  int ret = 0;
  vector<int> theVector;
  theVector.push_back(2);
  theVector.push_back(1);
  vector<int>::iterator vi;
  for(vi = theVector.begin(); vi != theVector.end(); vi++) {
    if (*vi == 1) {
      theVector.erase(vi);
    }
  }
  return ret;
}
```

4.4.1 Solution

The problem lies in the fact that erasing invalidates all subsequent iterators. In order to erase some iterators subject to certain conditions, one must first remove them to the end of the vector and then erase the end.

```
#include<vector>
#include<iostream>
#include<algorithm>
int main(int argc, char** argv) {
  using namespace std;
  int ret = 0;
  vector<int> theVector;
  theVector.push_back(2);
  theVector.push_back(1);
  vector<int>::iterator theEnd = remove(theVector.begin(), theVector.end(), 1);
  theVector.erase(theEnd, theVector.end());
  for(int i = 0; i < theVector.size(); i++) {
    cout << theVector[i] << endl;
  }
  return ret;
}
```

Chapter 5

A full-blown application

In this chapter we will describe in a step-by-step fashion how to build a full-blown application in C++. The application is called WET (WWW Exploring Topologizer) and its purpose is to explore a neighbourhood of a given URL in the World Wide Web and to output it in the shape of a graph. We delegate graph visualization to the GraphViz library `www.graphviz.org`, and in particular to the `dot` and `neato` UNIX utilities. These accept the input graph in a particular format

```
digraph graphName {
# list of nodes with special properties
  0 [ label = "thenode", color = red ];
# list of arcs
   0 -> 1;
   1 -> 2;
}
```

So the task performed by WET is to download a given URL and explore its links up to the n-th recursion level, then to put the obtained graph in the above format.

This chapter starts with a section on the software architecture; each class is then described and its implementation mostly delegated as exercise. The software architecture section does not contain any exercises, but it is a prerequisite for understanding what follows. Moreover, it is a (crude) example showing how to formalize the architecture of a software.

5.1 The software architecture

5.1.1 Description

Given an URL, this tool explores a local neighbourhood of the URL. Each web page is represented by a vertex in a graph, and given two vertices u, v there is an arc between them if there is a hyperlink citing the web page v in the web page u. The graph is then printed on the screen.

5.1.2 Formalization of requirements

- Input:
    - the URL we must start the retrieval from

  - the maximum hyperlink depth

- Output:

  - graph and time when the exploration was undertaken shown on screen

5.1.3 Modularization of tasks

- web page retrieval: downloads the HTML page for a given URL
- web page parser: finds all the hyperlinks in a given HTML page
- watch: returns the current time
- graph: stores vertices, arcs and a timestamp; outputs the graph to screen

5.1.4 Main algorithm

1. Input options and necessary data (from command line)
2. Start recursive URL retrieval algorithm

```
retrieveData(URL, maxDepth, Graph) {
  get current timestamp;
  store timestamp in graph
  retrieveData(URL, maxDepth, Graph, 0);
}
store graph on disk

retrieveData(URL, maxDepth, Graph, currentDepth) {
  if (currentDepth < maxDepth) {
    retrieve URL;
    parse HTML, get list of sub-URLs;
    for each sub-URL in list {
      store arc (URL, sub-URL) in graph
      retrieveData(sub-URL, maxDepth, graph, currentDepth + 1);
    }
  }
}
```

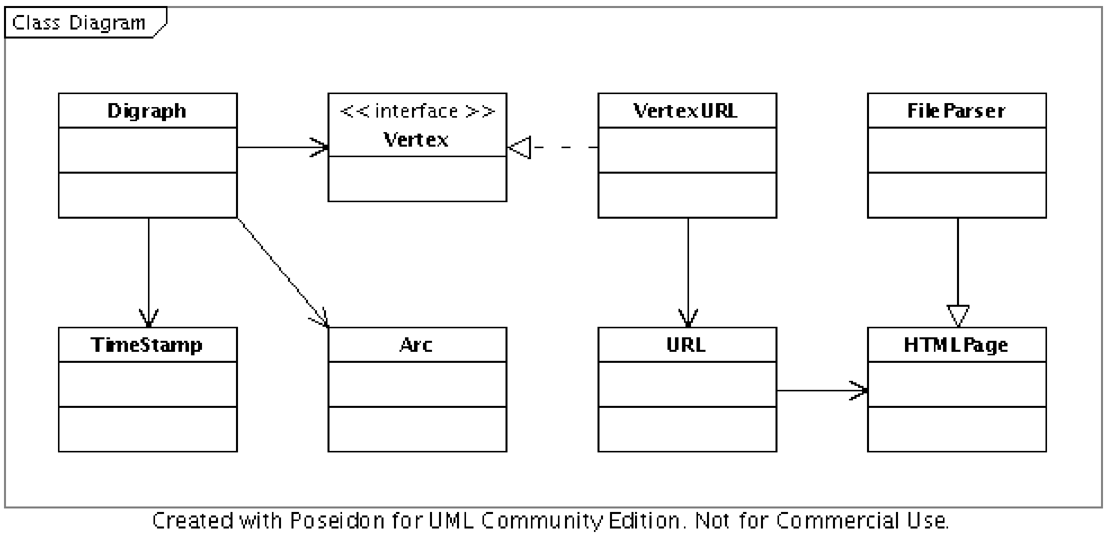
5.1.5 Fundamental data structures

- URL
- timestamp
- vertex
- arc
- graph

5.1.6 Classes

```
class TimeStamp; // stores a time stamp
class fileParser; // parses text files for tag=value (or tag="value") cases
class HTMLPage : public fileParser; // stores an HTML page
class URL; [contains HTMLPage object] // retrieves an HTML page
class Vertex; // public virtual class for a vertex
class VertexURL : public virtual Vertex; [contains URL] // implements a vertex
class Arc; [contains two Vertex objects] // arc
class Digraph; [contains a list of arcs and a timestamp] // graph
```

The diagram below shows the class interactions.



5.2 The TimeStamp class

Design and implement a class called `TimeStamp` managing the number of seconds elapsed since 1/1/1970. The class should have three methods: `long get(void)` to get the number of seconds since 1/1/1970, `void set(long t)` to set it, `void update(void)` to read it off the operating system. Furthermore, it must be possible to pass a `TimeStamp` object (call it `timeStamp`) on to a stream, as follows: `cout << timeStamp;` to obtain the date pointed at by `timeStamp`. Failures should be signalled by throwing an exception called `TimeStampException`.

You can use the following code to find the number of seconds elapsed since 1970 from the operating system:

```
#include<sys/time.h>
[...]
struct timeval tv;
struct timezone tz;
int retVal = gettimeofday(&tv, &tz);
long numberOfSecondsSince1970 = tv.tv_sec;
```

The following code transforms the number of seconds since 1970 into a meaningful date into a string:

```
#include<string>
#include<ctime>
#include<cstring>
[...]
time_t numberOfSecondsSince1970;
char* buffer = ctime(&numberOfSecondsSince1970);
buffer[strlen(buffer) - 1] = '\0';
std::string theDateString(buffer);
```

Write the class declaration in a file called `timestamp.h` and the method implementation in `timestamp.cxx`. Test your code with the following program `tsdriver.cxx`:

```
#include<iostream>
#include "timestamp.h"

int main(int argc, char** argv) {
  using namespace std;
  TimeStamp theTimeStamp;
  theTimeStamp.set(999999999);
  cout << "seconds since 1/1/1970: " << theTimeStamp.get()
       << " corresponding to " << theTimeStamp << endl;
  theTimeStamp.update();
  cout << theTimeStamp << " corresponds to " << theTimeStamp.get()
       << " number of seconds since 1970" << endl;
  return 0;
}
```

and verify that the output is:

```
seconds since 1/1/1970: 999999999 corresponding to Sun Sep  9 03:46:39 2001
Mon Sep 11 11:33:42 2006 corresponds to 1157967222 number of seconds since 1970
```

The solution to this exercise is included as an example of coding style. The rest of the exercises in this chapter should be solved by the student.

5.3 The `FileParser` class

Design and implement a class called `FileParser` that scans a file for a given string tag followed by a character `'='` and then reads and stores the string after the `'='` either up to the first space character or, if an opening quote character `'"'` is present after `'='`, up to the closing quote character. The class functionality is to be able to detect all contexts such as `tag = string` or `tag = "string"` in a text file, store the `string`s and allow subsequent access to them.

The class should be declared in `fileparser.h` and implemented in `fileparser.cxx`. You can use the following header code for class declaration.

```
/*****************************************************************
```

```
** Name:        fileparser.h
** Author:      Leo Liberti
** Source:      GNU C++
** Purpose:     www exploring topologizer - file parser (header)
** History:     060820 work started
*****************************************************************/

#ifndef _WETFILEPARSERH
#define _WETFILEPARSERH

#include<string>
#include<vector>

class FileParserException {
 public:
  FileParserException();
  ~FileParserException();
};

class FileParser {

 public:
  FileParser();
  FileParser(std::string theFileName, std::string theParseTag);
  ~FileParser();

  void setFileName(std::string theFileName);
  std::string getFileName(void) const;
  void setParseTag(std::string theParseTag);
  std::string getParseTag(void) const;

  // parse the file and build the list of parsed strings
  void parse(void) throw(FileParserException);

  // get the number of parsed strings after parsing
  int getNumberOfParsedStrings(void) const;

  // get the i-th parsed string
  std::string getParsedString(int i) const throw(FileParserException);

 protected:
  std::string fileName;
  std::string parseTag;

  // compare two strings (case insensitive), return 0 if equal
  int compareCaseInsensitive(const std::string& s1,
                             const std::string& s2) const;

  // return true if s2 is the tail (case insensitive) of string s1
  bool isTailCaseInsensitive(const std::string& s1,
                             const std::string& s2) const;

 private:
  std::vector<std::string> parsedString;
};

#endif
```

Pay attention to the following details:

- It is good coding practice to provide all classes with a set of get/set methods to access/modify internal (private) data.
- The `compareCaseInsensitive` and `isTailCaseInsensitive` methods are declared `protected` because they may not be accessed externally (i.e. they are for the class' private usage) but it may be useful to make them accessible to derived classes. Here is the definition of these two (technical) methods:

```
int FileParser::compareCaseInsensitive(const std::string& s1,
                                       const std::string& s2) const {
  using namespace std;
  string::const_iterator p1 = s1.begin();
  string::const_iterator p2 = s2.begin();
  while(p1 != s1.end() && p2 != s2.end()) {
    if (toupper(*p1) < toupper(*p2)) {
      return -1;
    } else if (toupper(*p1) > toupper(*p2)) {
      return 1;
    }
    p1++;
    p2++;
  }
  if (s1.size() < s2.size()) {
    return -1;
  } else if (s1.size() > s2.size()) {
    return 1;
  }
  return 0;
}

bool FileParser::isTailCaseInsensitive(const std::string& s1,
                                       const std::string& s2) const {
  using namespace std;
  int s2len = s2.size();
  if (s1.size() >= s2.size() &&
      compareCaseInsensitive(s1.substr(s1.size() - s2len, s2len), s2) == 0) {
    return true;
  }
  return false;
}
```

- In order to write the `parse` method, you have to scan the file one character at a time. The parser can be in any of the following three states: `outState`, `inTagState`, `inValueState`. Normally, the status is `outState`. When the parse tag is detected, a transition is made to `inTagState`. After that, if an 'equal' character (`'='`) is found, another transition is made to `inValueState`. The parser has three different behaviours, one in each state. When in `outState`, it simply looks for the parse tag `parseTag`. When in `inTagState`, it looks for the character `'='`, when in `inValueState`, it stores the value up to the first separating space or between quotes.

- The following code can be used to open a file and scan it one character at a time:

```
#include<iostream>
#include<fstream>
#include<istream>
#include<sstream>
#include<iterator>
[...]
// opens the file for input
string fileName("myfilename.ext");
ifstream is(fileName.c_str());
if (!is) {
  // can't open file, throw exception
}
// save all characters to a string buffer
char nextChar;
stringstream buffer;
while(!is.eof()) {
  is.get(nextChar);
  buffer << nextChar;
}
// output the buffer
cout << buffer.str() << endl;
// erase the buffer
buffer.str("");
```

- You can test your code with the following program `fpdriver.cxx`:

```
#include<iostream>
#include "fileparser.h"

int main(int argc, char** argv) {
  using namespace std;
  if (argc < 3) {
    cerr << "missing 2 args on cmd line" << endl;
    return 1;
  }
  FileParser fp(argv[1], argv[2]);
  fp.parse();
  for(int i = 0; i < fp.getNumberOfParsedStrings(); i++) {
    cout << fp.getParsedString(i) << endl;
  }
  return 0;
}
```

Make a small HTML file as follows, and call it `myfile.html`:

```
<html>
  <head>
    <title>MyTitle</title>
  </head>
  <body>
    My <a href="http://mywebsite.com/mywebpage.html">absolute link</a>
     and my <a href="otherfile.html">relative link</a>.
  </body>
</html>
```

Now run the `fpdriver` code as follows: `./fpdriver myfile.html href`, and verify that it produces the following output:

```
http://mywebsite.com/mywebpage.html
otherfile.html
```

5.4 The `HTMLPage` class

Design and implement a class called `HTMLPage` which inherits from `FileParser`. It should have the following functionality: opens an HTML file (of which the URL is known), reads and stores its links (transforming relative links into absolute links), allows external access to the stored links. This class is derived from `FileParser` because it uses `FileParser`'s functionality in a specific manner, performing some specific task (relative links are transformed into absolute links) of which `FileParser` knows nothing about.

- A link in an HTML page is the value in the tag `href="value"` (or simply `href=value`). HTML is a case insensitive language, so you may also find `HREF` instead of `href`.
- A WWW link is *absolute* if it starts with `http://` and a DNS name and is relative otherwise. Given a relative link (i.e. not starting with a slash '/' character, e.g. `liberti/index.html`) and an absolute link (e.g. `http://www.lix.polytechnique.fr/users`), the relative link is transformed into an absolute link by concatenating the two URLs (absolute and relative) with any missing slashes in between (e.g. `http://www.lix.polytechnique.fr/users/liberti/index.html`. On the other hand, if the relative link starts with a slash '/' (e.g. `/ liberti/index.html`) then the transformation of the relative link to absolute occurs by concatenating the first part of the absolute link (up to and including the DNS name) and the relative one (e.g. `http://www.lix.polytechnique.fr/~liberti/index.html`).
- Remember that not all links found next to HREF tags are valid HTTP links, some may concern different protocols. You should make sure that the link introduced by HREF is either relative (in which case you should make it absolute as explained above) or specifically an `http` link.
- Test your class implementation using the following driver `hpdriver.cxx`:

```
#include<iostream>
#include "htmlpage.h"

int main(int argc, char** argv) {
  using namespace std;
  if (argc < 3) {
    cerr << "missing 2 args on cmd line" << endl;
    return 1;
  }
  HTMLPage hp(argv[2], argv[1]);
  for(int i = 0; i < hp.getNumberOfLinks(); i++) {
    cout << hp.getLink(i) << endl;
  }
  return 0;
}
```

and check that the output of the command `./hpdriver http://127.0.0.1 myfile.html` is

```
http://mywebsite.com/mywebpage.html
http://127.0.0.1/otherfile.html
```

5.5 The URL class

Design and implement a class called `URL` containing a pointer to an `HTMLPage` object. Its functionality is to download an HTML file from the internet given its URL, and to allow access to the links contained therein.

- We shall make use of the `wget` external utility to download the HTML file. This can be used from the shell: `wget http://my.web.site/mypage.html` will download the specified URL to a local file called `mypage.html`. We can specify the output file with the option `-O output_file_name`. In order to call an external program from within C++, use the following code.

```
#include<cstdlib>
[...]
char charQuote = '\"';
string theURL = "http://127.0.0.1/index.html";
string outputFile = ".wet.html";
string cmd = "wget --quiet -O " + outputFile + " " + charQuote + theURL + charQuote;
int status = system(cmd.c_str());
```

- You will need to delete the temporary file `.wet.html` after having parsed it — use the following code.

```
#include<unistd.h>
[...]
unlink(outputFile.c_str());
```

- The `URL` class will expose a method `std::string getNextLink(void)` to read the links in the downloaded HTML page in the order in which they appear. Each time the method is called, the next link is returned. When no more links are present, the empty string should be returned. Subsequent calls to `getNextLink()` should return the sequence of links again as in a cycle.
- The `URL` class will contain a pointer to an `HTMLPage` object which parses the HTML code and finds the relevant links. Note that this means that a user memory allocation/deallocation will need to be performed.
- Test your `URL` implementation using the driver program `urldriver.cxx`:

```
#include<iostream>
#include "url.h"

int main(int argc, char** argv) {
  using namespace std;
  if (argc < 2) {
    cerr << "missing arg on cmd line" << endl;
    return 1;
  }
  URL url(argv[1]);
  url.download();
  string theLink = url.getNextLink();
  while(theLink.size() > 0) {
    cout << theLink << endl;
    theLink = url.getNextLink();
  }
  return 0;
}
```

Run the program

```
./urldriver http://www.enseignement.polytechnique.fr/profs/informatique/Leo.
Liberti/test.html
```

and verify that the output is

```
http://www.enseignement.polytechnique.fr/profs/informatique/Leo.Liberti/test3.html
http://www.enseignement.polytechnique.fr/profs/informatique/Leo.Liberti/test2.html
```

5.6 The Vertex interface and VertexURL implementation

Design and implement a class `VertexURL` inheriting from the pure virtual class `Vertex`:

```
/*******************************************************
** Name:        vertex.h
** Author:      Leo Liberti
** Source:      GNU C++
** Purpose:     www exploring topologizer -
**              vertex abstract class (header)
** History:     060820 work started
*******************************************************/

#ifndef _WETVERTEXH
#define _WETVERTEXH

#include<iostream>

class Vertex {
 public:
  virtual ~Vertex() {
#ifdef DEBUG
    std::cerr << "** destroying Vertex " << this << std::endl;
#endif
  }
  virtual int getID(void) const = 0;
  virtual int getNumberOfAdjacentVertices(void) const = 0;
  virtual int getAdjacentVertexID(int i) const = 0;
  virtual void addAdjacentVertexID(int ID) = 0;
};

#endif
```

`VertexURL` is an encapsulation of a `URL` object which conforms to the `Vertex` interface. This will be used later in the `Digraph` class to store the vertices of the graph. This separation between the `Vertex` interface and its particular implementation (for example the `VertexURL` class) allows the `Digraph` class to be re-used with other types of vertices, and therefore makes it very useful. An object conforming to the `Vertex` interface must know its own integer ID and IDs of the vertices adjacent to it. Note that `Vertex` has a virtual destructor for the following reason: should any agent attempt a direct deallocation of a `Vertex` object, the destructor actually called will be the destructor of the interface implementation (`VertexURL` in this case, but might be different depending on run-time conditions) rather than the interface destructor.

Test your implementation on the following code:

```
#include<iostream>
#include "vertexurl.h"

int main(int argc, char** argv) {
  using namespace std;
  if (argc < 2) {
    cerr << "missing arg on cmd line" << endl;
    return 1;
  }
  URL* urlPtr = new URL(argv[1]);
  urlPtr->download();
  VertexURL* vtxURLPtr = new VertexURL(0, urlPtr);
  Vertex* vtxPtr = vtxURLPtr;
  vtxPtr->addAdjacentVertexID(1);
  vtxPtr->addAdjacentVertexID(2);
  int starsize = vtxPtr->getNumberOfAdjacentVertices();
  cout << "vertex " << vtxPtr->getID() << ": star";
  for(int i = 0; i < starsize; i++) {
    cout << " " << vtxPtr->getAdjacentVertexID(i);
  }
  cout << endl;
  delete vtxPtr;
  return 0;
}
```

Run the program `./vurldriver http://kelen.polytechnique.fr` and verify that the output is `vertex 0: star 1 2`.

5.7 The `Arc` and `Digraph` classes

1. Design and implement an `Arc` class to go with the `Vertex` class above. In practice, an `Arc` object just needs to know its starting and ending vertex IDs.
2. Design and implement a `Digraph` class to go with the `Vertex` and `Arc` classes defined above. This needs to store a `TimeStamp` object, a vector of pointers to `Vertex` objects, a vector of pointers to `Arc` objects. We need methods both for constructing (`addVertex`, `addArc`) as well as accessing the graph information (`getNumberOfVertices`, `getNumberOfArcs`, `getVertex`, `getArc`). We also want to be able to send a `Digraph` object to the `cout` stream to have a GraphViz compatible text output which we shall display using the GraphViz utilities.

Test your implementation on the following program `dgdriver.cxx`:

```
#include<iostream>
#include "digraph.h"

int main(int argc, char** argv) {
  using namespace std;
  string urlName1 = "name1";
  string urlName2 = "name2";
  string urlName3 = "name3";
  URL* urlPtr1 = new URL(urlName1);
  URL* urlPtr2 = new URL(urlName2);
  URL* urlPtr3 = new URL(urlName3);
  VertexURL* vtxURLPtr1 = new VertexURL(1, urlPtr1);
  VertexURL* vtxURLPtr2 = new VertexURL(2, urlPtr2);
  VertexURL* vtxURLPtr3 = new VertexURL(3, urlPtr3);
  Vertex* vtxPtr1 = vtxURLPtr1;
  Vertex* vtxPtr2 = vtxURLPtr2;
  Vertex* vtxPtr3 = vtxURLPtr3;
  vtxPtr1->addAdjacentVertexID(2);
  vtxPtr1->addAdjacentVertexID(3);
  vtxPtr2->addAdjacentVertexID(1);
  vtxPtr3->addAdjacentVertexID(3);
  Arc* arcPtr1 = new Arc(1,2);
  Arc* arcPtr2 = new Arc(1,3);
  Arc* arcPtr3 = new Arc(2,1);
  Arc* arcPtr4 = new Arc(3,3);
  TimeStamp t;
  t.update();
  Digraph G;
  G.setTimeStamp(t);
  G.addVertex(*vtxPtr1);
  G.addVertex(*vtxPtr2);
  G.addVertex(*vtxPtr3);
  G.addArc(*arcPtr1);
  G.addArc(*arcPtr2);
  G.addArc(*arcPtr3);
  G.addArc(*arcPtr4);
  cout << G;
  return 0;
}
```

and verify that the output is:

```
# graphviz output by WET (L. Liberti 2006)
digraph www_1158015497 {
  0 [ label = "Tue Sep 12 00:58:17 2006", color = red ];
   1 -> 2;
   1 -> 3;
   2 -> 1;
   3 -> 3;
}
```

5.8 Putting it all together: `main()`

Code the `main` function and all auxiliary functions into the files `wet.h` (declarations) and `wet.cxx` (definitions). The program should: read the given URL and the desired downloading recursion depth limit from the command line, then recursively download the given URL and all meaningful sub-links up to the given depth limit, whilst storing them as vertices and arcs of a digraph, which will then be printed out in GraphViz format.

- The recursive part of the algorithm can be coded into a pair of functions (one is the "driver" function, the other is the truly recursive one) declared as follows:

```
// retrieve the data, driver
void retrieveData(std::string URL, int maxDepth, Digraph& G,
                  bool localOnly, bool verbose);
// retrieve the data, recursive
void retrieveData(std::string URL, int maxDepth, Digraph& G,
                  bool localOnly, bool verbose,
                  int currentDepth, VertexURL* vParent);
```

(also see Section 5.1.4).

- Endow your WET application with a command line option `-v` (stands for "verbose") that prints out the URLs as they are downloaded
- Endow your WET application with a command line option `-l` (stands for "local") that ignores all URLs referring to webservers other than localhost (127.0.0.1). **Optional**: also try to devise an option `-L` that ignores all URLs referring to webservers different from the one given on command line.
- The GraphViz system can read a text description of a given graph and output a graphical representation of the graph in various formats. The WET application needs to output the text description of the `Digraph` object. One self-explanatory example of the required format has been given at the beginning of this chapter. You can type `man dot` at the shell to get more information. Implement WET so that it outputs the graph description in the correct format on `cout`. When your WET application is complete, run it so that it saves the output to a file with the `.dot` extension: `./wet http://kelen.polytechnique.fr/ 3 > mygraph.dot`. The command `dot -Tgif -o mygraph.gif mygraph.dot` builds a GIF file which you can display using the command `xv mygraph.gif`.

Test your WET application by running
`[./wet http://www.enseignement.polytechnique.fr/profs/informatique/Leo.Liberti/test.html 4]` and verifying that the output is

```
# graphviz output by WET (L. Liberti 2006)
digraph www_1158043952 {
  0 [ label = "Tue Sep 12 08:52:32 2006", color = red ];
   0 -> 1;
   1 -> 0;
   1 -> 2;
   2 -> 0;
   2 -> 1;
   0 -> 2;
}
```

By saving `wet`'s output as `wetout.dot` and running `dot -Tgif -o wetout.gif wetout.dot` we get Fig. 5.1, left. Reducing the depth level to 2 yields Fig. 5.1, right.

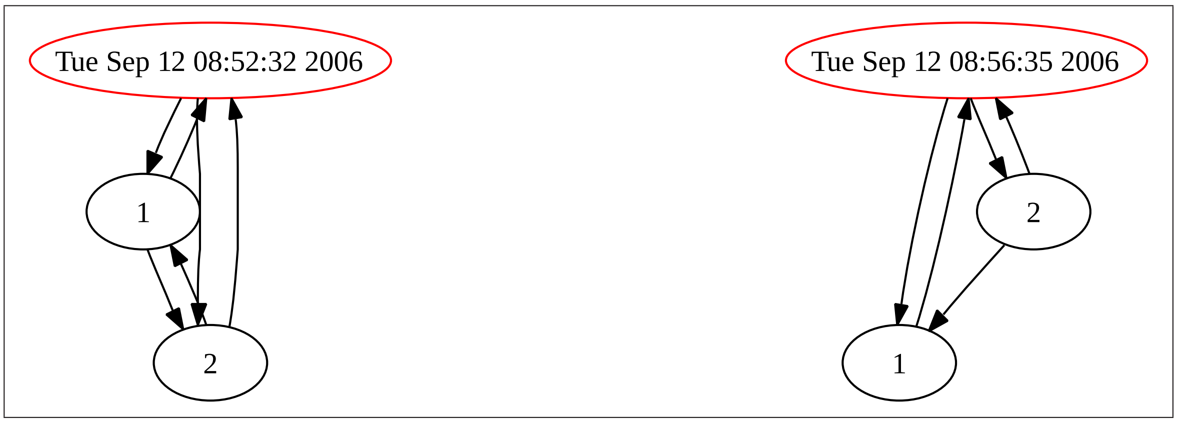


Figure 5.1: The neighbourhoods graphs (depth 4, left; depth 2, right).

Chapter 6

Exam questions

This section contains a set of typical exam questions.

6.1 Debugging question 1

The following code causes some compilation errors. Find them and correct them.

```
// this code contains errors
#include <iostream>
#include <cassert>

int main(int argc, char** argv) {
  int ret = 0;
  if (argc < 2) {
    cerr << "error: need an integer on command line";
    return 1;
  }
  int theInt = atoi(argv[1]);
  if (isPrime(theInt)) {
    cout << theInt << "is a prime number!" >> endl;
  } else {
    cout << theInt << "is composite" << endl;
  return ret;
}

bool isPrime (int num) {
  assert(num >= 2);
  if (num == 2) {
    return true;
  } else if (num % 2 == 0) {
    return false;
  } else {
    bool prime = true;
    int divisor = 3;
    int upperLimit = sqrt(num) + 1;
    while (divisor <= upperLimit) {
      if (num % divisor == 0) {
        prime = false;
      }
      divisor +=2;
    }
    return prime;
  }
}
```

What is the corrected program output when executed with `./debug1 1231`?

6.2 Debugging question 2

The following code causes some compilation errors. Find them and correct them.

```
// this code contains errors
#include <iotsream>

class A {
  A() {
    std::cout << "constructing object of class A" << std::endl;
  }
  ~A() {
    std::cout << "destroying object of class A" << std::endl;
  }
  setDatum(int i) {
    theDatum = i;
  }
  getDatum(void) {
    return theDatum;
  }
private:
  int theDatum;
}

int main(int argc, char** argv) {
  A a;
  a.SetDatum(5);
  std::cout << a.GetDatum() << std::endl;
  return;
}
```

What is the corrected program output when executed with `./debug2`?

6.3 Debugging question 3

The following code looks for a word in a text file and replaces it with another word:

```
// this code contains errors
// [search and replace a word in a text file]
#include<iostream>
#include<fstream>
#include<string>
int main(int argc, char** argv) {
  using namespace std;
  if (argc < 4) {
    cout << "need a filename, a word and its replacement on cmd line" << endl;
    return 1;
  }
  ifstream ifs(argv[1]);
  if (!ifs) {
    cout << "cannot open file " << argv[1] << endl;
    return 2;
  }
  string s;
  while(!ifs.eof()) {
    ifs >> s;
    if (ifs.eof()) {
      break;
    }
    if (s == argv[2]) {
      cout << argv[3];
    } else {
      cout << s;
    }
    cout << " ";
  }
  cout << endl;
  ifs.close();
  return 0;
}
```

Test it on the folling file, called `story.txt`, with the command `./debug3 story.txt wolf teddy-bear`:

```
This is just a stupid little story with no meaning whatsoever. The wolf
came out of his den and chased little red hood, found her and pounced on
her. Little red hood cried, "the wolf!", just stepped aside and the
wolf cracked his neck on the pavement, his brain in pulp.
She was to hear of him no more.
```

The output is:

```
This is just a stupid little story with no meaning whatsoever. The teddy-bear
came out of his den and chased little red hood, found her and pounced on her.
Little red hood cried, "the wolf!", just stepped aside and the
teddy-bear cracked his neck on the pavement, his brain in pulp. She was to
hear of him no more.
```

Note that one occurrence of the word “wolf” was not actually changed to “teddy-bear”. Fix this problem.

6.4 Debugging question 4

Compile and run the following code:

```
// if you change t with s in the snippet, the code has the same effect
#include<iostream>
#include<string>

std::string method(std::string& s) {
  s = s.substr(1, s.npos);
  return s;
}

int main(int argc, char** argv) {
  using namespace std;
  string s("ciao");
  cout << s << endl;
  while(true) {
    string& t = s;
    //////////// snippet ////////////////
    t = method(t);
    if (t.length() == 0) {
      break;
    }
    cout << t << endl;
    //////////// end snippet ////////////
  }
  return 0;
}
```

the output is:

```
ciao
iao
ao
o
```

Now examine the part of the code marked "snippet": it has the curious property that if you replace any occurrence of the `t` variable symbol with the `s` variable symbol, you still obtain the same output. Explain why.

6.5 Debugging question 5

The following code contains a simple list implementation and a `main()` which creates a list, prints it, finds a node and removes it, then prints the list again.

```
// this code contains errors
// [form and print a list of integers]
#include <iostream>
```

```
class Node {
public:
  // constructors / destructor
  Node() : next(NULL), previous(NULL) { }
  Node(int a) : next(NULL), previous(NULL), data(a) { }
  ~Node() {
    if (next) {
      delete next;
    }
  }

  // set/get interface
  void setData(int a) {
    data = a;
  }
  int getData(void) {
    return data;
  }
  void setNext(Node* theNext) {
    next = theNext;
  }
  Node* getNext(void) {
    return next;
  }
  void setPrevious(Node* thePrevious) {
    previous = thePrevious;
  }
  Node* getPrevious(void) {
    return previous;
  }

  // list capabilities

  // return true if node is the first of the list, false otherwise
  bool isFirst(void) {
    return !previous;
  }

  // return true if node is the last of the list, false otherwise
  bool isLast(void) {
    return !next;
  }

  // return the size of the sublist starting from this node
  int size(void) {
    Node* t = this;
    int ret = 1;
    while(!t->isLast()) {
      t = next;
      ret++;
    }
    return ret;
  }
  // append a new given node at the end of the list
  void append(Node* theNext) {
    Node* t = this;
    while(!t->isLast()) {
      t = next;
    }
    t->setNext(theNext);
    theNext->setPrevious(t);
  }

  // create a new node with value 'a' and append it at the end of the list
  void appendNew(int a) {
    Node* t = this;
    while(!t->isLast()) {
      t = next;
    }
    Node* theNewNode = new Node(a);
    t->setNext(theNewNode);
    theNewNode->setPrevious(t);
  }

  // remove this node from the list
  void erase(void) {
    previous->setNext(next);
    next->setPrevious(previous);
  }

  // replace this node with a given node
  void replaceWith(Node* replacement) {
    previous->setNext(replacement);
    next->setPrevious(replacement);
  }

  // find first node with a specified value in sublist starting from this node
  // return NULL if not found
  Node* find(int needle) {
    if (data == needle) {
      return this;
    }
    Node* t = this;
    while(!t->isLast()) {
      t = next;
      if (t->getData() == needle) {
        return t;
      }
    }
    return NULL;
  }

  // print the data in the sublist starting from this node
  void print(void) {
    Node* t = this;
    while(!t->isLast()) {
      std::cout << t.getData() << ", ";
      t = next;
    }
    std::cout << t->getData() << std::endl;
  }

protected:
  // pointer to next node in list
  Node* next;

  // pointer to previous node in list
  Node* previous;

private:
  // the integer data stored in the node
  int data;
};

int main(int argc, char** argv) {
  using namespace std;
  int c = 1;
  // create a new list
  Node start(c);
  // add 10 nodes to the list
  while(c < 10) {
    c++;
    start.appendNew(c);
  }
  // print the list
  start.print();
  // find the node with value 5
  Node* t = start.find(5);
  // erase this node
  t->erase();
  // print the list again
  start.print();

  return 0;
}
```

The code contains:

1. one compilation error;
2. some run-time errors;
3. a memory leak.

Correct the compilation error, then compile the code — it should simply hang. Use the `ddd` debugger to find the run-time errors, find all instances thereof, and correct them (remember to compile with the `-g` option for debugging). Satisfy yourself that the code output is:

```
1, 2, 3, 4, 5, 6, 7, 8, 9, 10
1, 2, 3, 4, 6, 7, 8, 9, 10
```

Now use the `valgrind` memory debugger to check for memory leaks. Run the command

```
valgrind --leak-check=yes ./debug5
```

and using its output find and fix the error.

6.6 Debugging question 6

Compile the following code with `cc -o schnitzi schnitzi.c` and run it with `./schnitzi 36` to test it, and try other numbers. Explain what it does and why.

```
#include<stdio.h>
main(l,i,I)char**i;{l/=!(l>(I=atoi(*++i))||fork()&&main(l+1,i-1)||I%l);
return printf("%d\n",l);}
```

6.7 Specification coding question 1

Write the implementation of the following `SimpleString` class.

```
/* name: simplestring.h
** author: L. Liberti
*/

#ifndef _SIMPLESTRINGH
#define _SIMPLESTRINGH

#include<iostream>

class SimpleString {
 public:
  // default constructor: initialise an empty string
  SimpleString();

  // initialise a string from an array of characters
  SimpleString(char* initialiseFromArray);

  // destroy a string
  ~SimpleString();

  // return the size (in characters)
  int size(void) const;

  // return the i-th character (overloading of [] operator)
  char& operator[](int i);

  // copy from another string
  void copyFrom(SimpleString& s);
  // append a string to this
  void append(SimpleString& suffix);

  // does this string contain needle?
  bool contains(SimpleString& needle) const;

 private:

  int theSize;
  char* buffer;
  int theAllocatedSize;
  static const int theMinimalAllocationSize = 1024;
  char theZeroChar;
};

std::ostream& operator<<(std::ostream& out, SimpleString& s);

#endif
```

Test it with with the following `main` program:

```
/* name: ssmain.cxx
   author: Leo Liberti
*/

#include<iostream>
#include "simplestring.h"

int main(int argc, char** argv) {
  using namespace std;
  SimpleString s("I'm ");
  SimpleString t("very glad");
  SimpleString u("so tired I could pop");
  SimpleString v("very");
  cout << s << endl;
  cout << t << endl;
  cout << u << endl << endl;
  SimpleString w;
  w.copyFrom(s);
  s.append(t);
  w.append(u);
  cout << s << endl;
  cout << w << endl << endl;
  if (s.contains(v)) {
    cout << "s contains very" << endl;
  } else {
    cout << "s does not contain very" << endl;
  }
  if (w.contains(v)) {
    cout << "w contains very" << endl;
  } else {
    cout << "w does not contain very" << endl;
  }
  return 0;
}
```

and check that the output is as follows.

```
I'm
very glad
so tired I could pop

I'm very glad
I'm so tired I could pop

s contains very
w does not contain very
```

Write also a makefile for building the object file `simplestring.o` and the executable `ssmain`.

6.8 Specification coding question 2

Write the implementation of the following `IntTree` class (a tree data structure for storing integers).

```
/* Name:    inttree.h
   Author:  Leo Liberti
*/

#ifndef _INTTREEH
#define _INTTREEH

#include<vector>

class IntTree {
 public:
  // constructs an empty tree
  IntTree();

  // destroys a tree
  ~IntTree();

  // add a new subnode with value n
  void addSubNode(int n);

  // get the number of subtrees
  int getNumberOfSubTrees(void);

  // get a pointer to the i-th subtree
  IntTree* getSubTree(int i);

  // removes a subtree without deleting it (and returning it)
  IntTree* removeSubTree(int i);

  // adds a tree as a subtree of the current tree
  void addSubTree(IntTree* t);
  // get pointer to the parent tree
  IntTree* getParent(void);

  // set parent pointer
  void setParent(IntTree* p);

  // get value of current tree
  int getValue(void);

  // set value in current tree
  void setValue(int n);

  // find the first subtree containing given value by depth-first search
  // and put its pointer in 'found'
  // PRECONDITION: found must be NULL on entry
  // POSTCONDITION: if found is NULL on exit, value was not found
  void findValue(int n, IntTree* &found);

  // print a tree to standard output
  void print(void);

 protected:

  // value stored in the node (tree)
  int value;

  // pointer to parent tree
  IntTree* parent;

  // vector of subtree pointers
  std::vector<IntTree*> subTree;

 private:

  // iterator sometimes used in methods
  std::vector<IntTree*>::iterator stit;
};

#endif
```

Test it with with the following `main` program:

```
/* name:   itmain.cxx
   author: Leo Liberti
*/

#include <iostream>
#include "inttree.h"

int print(IntTree& t) {
  using namespace std;
  cout << "T = ";
  t.print();
  cout << endl;
}

int main(int argc, char** argv) {
  using namespace std;
  IntTree myTree;
  myTree.setValue(0);
  myTree.addSubNode(1);
  myTree.addSubNode(2);
  myTree.addSubNode(3);
  print(myTree);

  int st = myTree.getNumberOfSubTrees();
  for(int i = 0; i < st; i++) {
    IntTree* t = myTree.getSubTree(i);
    t->addSubNode(2*i + st);
    t->addSubNode(2*i + 1 + st);
  }
  print(myTree);

  IntTree* anotherTree = new IntTree;
  anotherTree->setValue(-1);
  anotherTree->addSubNode(-2);
  anotherTree->addSubNode(-3);

  IntTree* t = NULL;
  myTree.findValue(2, t);
  if (t) {
    st = t->getNumberOfSubTrees();
    IntTree* u = t->removeSubTree(st - 1);
    print(myTree);
    delete u;
    t->addSubTree(anotherTree);
  }
  print(myTree);

  myTree.findValue(-3, t);
  int level = 1;
  while(t != NULL) {
    t = t->getParent();
    level++;
  }
  cout << "node (-3) is at level " << level << " (root has level 1)" << endl;
  return 0;
}
```

and check that the output is as follows.

```
T = 0 ( 1 2 3 )
T = 0 ( 1 ( 3 4 ) 2 ( 5 6 ) 3 ( 7 8 ) )
T = 0 ( 1 ( 3 4 ) 2 ( 5 ) 3 ( 7 8 ) )
T = 0 ( 1 ( 3 4 ) 2 ( 5 -1 ( -2 -3 ) ) 3 ( 7 8 ) )
node (-3) is at level 3 (root has level 1)
```

6.9 Task question 1

Write a program that prints its own (executable) file size in bytes and in number of printable characters (a character `char c` is *printable* if `(isalnum(c) > 0 || ispunct(c) > 0 || isspace(c) > 0)`).

6.10 Task question 2

Write a program that prints the name of the image files referenced in the the web page `http://www.enseignement.polytechnique.fr/index.html`. Image files are referenced in HTML both by the attribute `HREF` of the tag `A` (e.g. `<A REF="http://website.com/image.jpg">`) and by the attribute `SRC` of the tag `IMG` (e.g. `<IMG SRC="/images/logo.gif">`). The output should be as follows.

```
images/entete1.gif
images/remise.gif
images/amphi.gif
/icones/home.gif
```

6.11 Task question 3

Write a program that reads an $m \times n$ matrix $A = (a_{ij})$ from a text file with m lines is a list of n `double` entries separated by a space, then output the homogeneous system $Ax = 0$ in explicit algebraic form with m lines of text having the following format:

a_{i1} `* x[1] + ...` a_{in} `* x[`n`].`

The name of the file containing the matrix and the integer n should be read from the command line.

For example, for the text file

```
1 -2.3 3 0.0
-9.123 2 -50 -1
```

you should obtain the following output:

```
x[1] - 2.3*x[2] + 3*x[3] = 0
-9.123*x[1] + 2*x[2] - 50*x[3] - x[4] = 0
```

Hint: if you have a file stream `ifs` and you want to read a double value off it, use the following construct.

```
double t;
ifs >> t;
```