Advanced programming with lcc-win32

by

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Chapter 1 Containers

2.1 Abstract data types

Abstract data types are abstractions from a data structure that consists of two parts: a *specification* and an *implementation*. The specification defines how the data is stored without any implementation details, a set of operations that the user can invoke on the stored data, and the error handling within the context of each operation.

For a single implementation of an abstract data type there can be many possible implementations. This implementations ca be changed at any time without any direct impact on the user because the interface between the abstract data type and its users remains the same. Of course, the user should see the impact of changing a slow implementation by a faster one, or even a buggy implementation by a correct one! What is meant here is that no changes should be necessary to his/her code to use the new implementation.

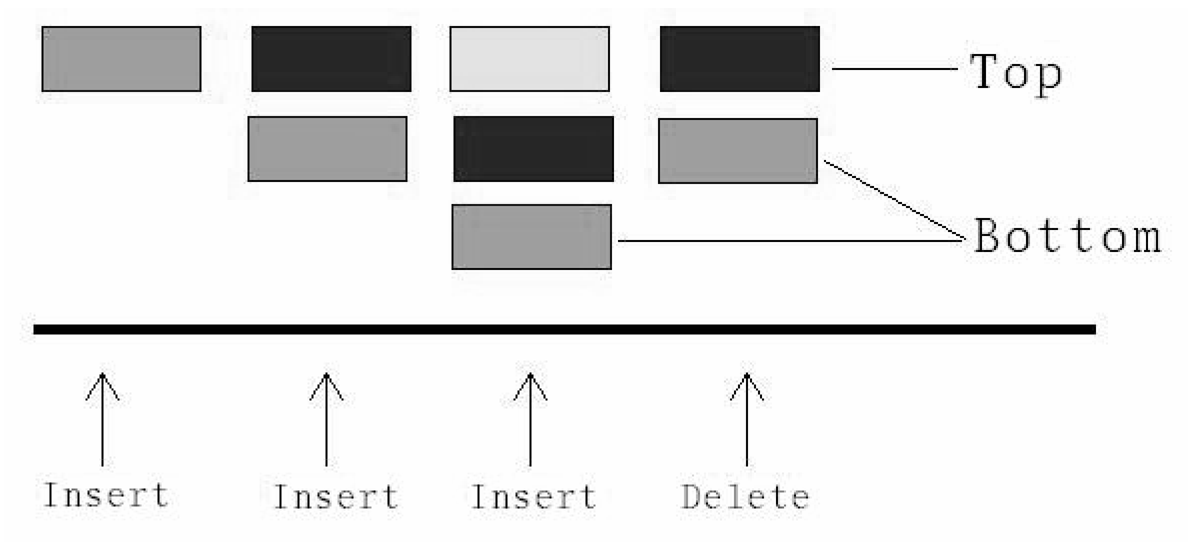
2.1.1 Stacks

The stack abstract data type stores objects in a last-in, first-out basis, i.e. the last object stored will be the first one to be retrieved. It supports basically only two operations:

1) Push: an object is stored in the stack. This object becomes the top of the stack, and the former top of stack is moved (conceptually) one place down.

2) Pop: an object is retrieved from the stack, and the object below the top object becomes the new top of the stack.

Stacks are implemented usually using an array or a list. Both arrays and list containers support the basic stack operations. We will discuss stacks more later in this chapter.



2.2 Strings

Strings are a fundamental data type for a wide type of applications. We have seen in the preceeding chapters the problems that C strings have. Here is a proposal for a string library that allows you to avoid those problems. It was started by Friedrich Dominicus, and after his initial push we have both worked together in this.

The whole source code is available to you for easy customization. At any time you can build a specialized version of it, to fit a special need or to change one of the design parameters.

The string library is based in the abstract notion of a container, i.e. a common set of interface functions, that allow you some latitude when building your program. Using the abstract indexing notation, you can change your data representation from a vector to an array, or even from a list to a vector without being forced to change a lot in your own programs.

Strings are a sequence of characters. We can use one or two bytes for storing characters. Occidental languages can use fewer characters than Oriental languages, that need two bytes to store extended alphabets. But occidentals too, need more than one byte in many applications where mathematical symbols, drawings and icons increase the size of the available alphabet beyond the 256 limit of a byte.

We classify then strings in multi_byte sequences of characters, (alphabet is smaller than 256) or wide character strings, where the alphabet can go up to 65535 characters. The library handles both character types as equivalent.

The definition of a string looks like this:

```
typedef struct _String {
     size_t count;
     unsigned char *data;
     size_t capacity;
} String;
```

The count field indicates how many characters are stored in the String. Follows the data pointer, the allocated size, and the type of the string: either one or two bytes characters.

We store a pointer to the data instead of storing the data right behind the descriptor. We waste then, sizeof(void *) for each string but this buys an increased flexibility. Strings are now resizable since we can change the pointer and reallocate it with a different size without having to allocate a new string. This is important since if there are any pointers to this string they will still be valid after the resize operation, what would not be the case if we had stored the characters themselves in the data structure.

Text is stored either coded in one byte characters, or in UNICODE (multi-byte) numbers of two bytes. For each type of string there are two functions. For instance for copying a string there is the Strcpy function, that has two flavors, StrcpyA for copying single byte strings, and StrcpyW for copying wide char strings.

You can use the generic names with only one type of strings, either wide or ascii, but not both. These names are implemented like this:

```
#ifdef UNICODE
#define Strcpy StrcpyW
#else
#define Strcpy StrcpyA
#endif
```

Of course both functions are available, if called explicitly.

The advantage of this schema is that there is only one set of names and a simple rule for using all the string functions. To copy a string you use Strcpy period.

The functions are patterned after the traditional C functions, but several functions are added to find sets of characters in a string, or to read a file into a string.

In general, the library tries as hard as possible to mimic the known functions and notation of the existing C strings.

The string library introduces the concept of iterators, or fat pointers. This data structure consists of a pointer to some character within the container, in this case the string, a count, and a pointer to the whole strings. String pointers are called Stringp, and they come in two flavors too: wide and single byte strings.

There are two properties of the string you will want to have access to: its length, and its capacity. The length is the number of characters that the string contains, and the capacity is the number of characters the string can store before a resize operation is needed. You can access those properties with

```
String s1;
...
int len = get_size(s1);
```

2.2.1 Design criteria

What are the design decisions that make the base of the library?

2.2.1.1 Memory management

The first versions of the library contained for each container a pair of pointers for the memory allocation and memory release functions. This increases the size of the library, and considerably increases the number of things that can go wrong.

Each container had its own memory management, for releasing elements and maintaining free lists. This was cumbersome and has been discarded. Memory management is better done by the memory manager, i.e. the garbage collector.

Since lcc-win32 features a garbage collector (GC) in the standard distribution, this simplifies the library. Other environments like Java or the recent.Net architecture of Microsoft feature as a standard library feature the garbage collector too.

2.2.2 The handling of exceptions

All containers check any indexed access for errors. Badly formed input is detected at run time and the program (by default) is stopped with an error message. Any of the functions in the interface can throw an exception if given incorrect inputs. This can be disabled by redefining the macro PRECONDITIONS to be an empty operation. This is surely not recommended, but the possibility exists.

Each routine in the library specifies in the PRECONDITIONS section the terms of the contract it has with its callers.

Internal routines, i.e. routines only called from within the library, can assume their inputs valid, and make less checks. That interface is not available to the user code however.

2.2.2.1 Efficiency considerations

The C language has an almost obsessive centering in "efficiency". Actually, as everybody knows, efficiency depends on the algorithm much more than in the machine efficiency with which operations are coded. Length delimited strings are by nature more efficient than normal C strings since the often used strlen operation takes just a memory read, instead of starting an unbounded pointer memory scan seeking the trailing zero.

Efficiency must be weighted against security too, and if we have to chose, when implementing the container library, security has been always more important than machine efficiency. Some operations like array bound checking can add a small overhead to the run time, but this will be of no concern to the vast majority of the applications done with this library. Using a hash table will be always more efficient than a plain linear scan through a hastily constructed table. Even if we code the table lookup in assembler.

In this version, efficiency has been left out. The weight of the effort has gone into making a library that works and has fewer bugs.

2.2.2.2 C and C++

If you know the C++ language, most of this things will sound familiar. But beware. This is not C++. There is no "object oriented" framework here. No classes, instantiated template traits, default template arguments casted for non "constness", default copy constructors being called when trying to copy a memory block. Here, a memory block copy is that: a memory block copy, and no copy constructors are called anywhere. Actually, there are no constructors at all, unless you call them explicitly.

You can do copy constructors of course, and the library provides copy_list, copy_bitstring, etc. But you call them explicitly, the compiler will not try to figure out when they should be called. All this makes programs clearer: we know what is being called, and the calls do not depend any more on the specific compiler version.

Yes, the compiler does some automatic calls for you. You can redefine operators, and you have generic functions. This introduces many problems you are aware of, if you know C++. Here however, the complexity is enormously reduced, since there are no systematic implicit calls, and objects are not automatically clustered in classes. You can make classes of objects of course, but you do it explicitly. No implicit conversions are grained in the language itself.

Here we have a library for using simple data structures. Nothing is hidden from view behind an opaque complex construct. You have the source and a customizing tool.

C has a formidable power of expression because it gives an accurate view of the machine, a view that has been quite successful.

C++ is a derived language from C. It introduced the notion of well classified “objects”, an idea that was put forward by many people, among others Betrand Meyer, and Xerox, with their Smalltalk system.

Unfortunately, what was a good paradigm in some situations becomes a nightmare in others. When we try to make a single paradigm a “fits all” solution, the mythical silver bullet, nothing comprehensible comes out. To be “object oriented” meant many things at once and after a while, nothing at all.

For C++ the object oriented framework meant that functions were to be called automatically by the compiler, for creating and destroying objects. The compiler was supposed to figure out all necessary calls. This is one solution for the memory management problem.

Another solution, and the one lcc-win32 proposes, is to use a garbage collector. C++ did not introduce a GC for reasons I have never understood. This solution is much simpler than making a complex compiler that figures out everything automatically. The destructor is the GC that takes care of the left overs of computation.

Then, it becomes possible to make temporary objects without worrying about who disposes of temps. The GC does. Operators can return dynamically allocated temporary objects without any problem. The equivalent of C++ automatic object destruction is attained with the GC, and the complexity of the software is reduced.

At the same time, bounds checked arrays and strings become possible. A general way of using arrays and other data structures is possible.

2.2.3 Description

2.2.3.1 Creating strings

The simplest way to create strings is to assign them a C string. For instance:

```
String s = "This is a string";
```

To allocate a string that will contain at least n characters you write:

```
String s = new_string(n);
```

The primitive new_string is a versatile function. It can accept also a character string:

```
String s = new_string("This is a string");
```

or a double byte character string:

```
String s new_string(L"This is a string");
```

2.2.3.2 Copying

When you assign a String to another, you make a *shallow* copy. Only the fields of the String structure will be copied, not the contents of the string. To copy the contents of the string you use the copy function or its synonym Strdup:

```
String s2 = copy(s1); // Equivalent to Strdup(s1);
```

Destructively copying a string is done with the Strcpy function.

```
String s1 = "a", s2 = "abcd";
Strcpy(s1,s2); // Now s1 contains “abcd”
```

To destructively copy a certain number of characters into another string, you use the Strncpy function:

```
String s1 = "abc", s2 = "123456789";
Strncpy(s1,s2,5); // Now s1 contains "12345";
```

2.2.3.3 Accessing the characters in a String

The [ ] notation is used to access the characters as in normal C character strings. Given the string:

```
String s1 = "abc";
```

you access each character with an integer expression:

```
int c = s1[1]; // Now c contains 'b'
```

You assign a character in the string with:

```
s1[0] = 'A';
```

Now the string contains “Abc”.

Note that mathematical operations with characters are not supported. You can’t write:

```
s1[0] += 2; // Wrong
```

The rationale behind this decision is that characters are characters and not numbers. You can of course do it if you do:

```
int c = s1[0];
c += 2;
s[0] = c;
```

Note that pointer notation is not supported. The construct:

```
*s1 = 'a';
```

is no longer valid. It must be replaced with

```
s1[0] = 'a';
```

2.2.3.4 Comparing strings

You can compare two strings with the == sign, or with the Strcmp function. Strcmp returns the lexicographical order (alphabet order) for the given strings. The equals sign just compares if the strings are equal. Both types of comparison are case sensitive. To use a case insensitive comparison use Strcmpi. Note that this implementation doesn’t support the case insensitive wide char comparison yet.

2.2.3.5 Relational operators

The relational operators can be defined like this:

```
int operator ==(const String & string1, const String & string2)
{
        if (isNullString(string2)  && isNullString(string1))
           return 1;
        if (isNullString(string2) || isNullString(string1))
           return 0;
        struct Exception *exc = GetAnExceptionStructure();
        PRECONDITION((Strvalid(string1) && Strvalid(string2)), exc);
        if (string1.count != string2.count)
           return 0;
        return !memcmp(string1.content,string2.content,string1.count);
}
```

We check for empty strings, that can be compared for equality without provoking any errors. Two empty strings are considered equal. If either of the strings is empty and the other isn’t, then they can’t be equal.

Those tests done, both strings must be valid. They are equal if their count and contents are equal. Note that we use memcmp and not strcmp since we support strings with embedded zeroes in them.

The wide character version differs from this one only in the length of the memory comparison.

The function “isNullString” tests for the empty string, i.e. a string with a count of zero, and contents NULL.

An empty string is returned by some functions of the library to indicate failure. It is semantically the same as the NULL pointer.

The other relational operators are a bit more difficult. Here is “less” for instance:

```
int operator < (const String & s1, const String &s2)
{
    bool s1null = isNullString(s1);
    bool s2null = isNullString(s2);
    if (s1null && s2null)
      return 0;
    if (s1null && !s2null)
      return 1;
    if (!s1null && s2null)
      return 0;
    struct Exception *exc = GetAnExceptionStructure();
    PRECONDITION((Strvalid(s1) && Strvalid(s2)), exc);
    if (s1.count == 0 && s2.count != 0)
      return 1;
    if (s1.count && s2.count == 0)
      return 0;
    int len = s1.count < s2.count ?
           s1.count : s2.count;
    return memcmp(s1.content, s2.content, len) < 0;
}
```

We have to differentiate between a NULL string, an empty string and a valid or invalid string. This is the same as in standard C where we differentiate between NULL and ““, the empty string. A pointer can have a NULL value, a valid value pointing to an empty string, or an invalid value pointing to nowhere.

We put NULL and empty strings at the start of the lexicographical order, so they are always less than non empty strings. Note that we compare only as much as the shorter of both strings. This is important, because we wouldn’t want that memcmp continues comparing after the end of the shorter string. Since we have the length of the string at hand, the operation is very cheap, a few machine instructions.

2.2.3.6 Dereferencing strings

Another operator worth mentioning is the pointer dereference operator ‘*’.

In C, a table is equivalent to a pointer to the first element. With the definitions:

```
    char str[23];
    *str = 0;
```

The expression *str = 0 is equivalent to str[0] = 0. We can mimic this operation with the redefinition of the ‘*’ operator:

```
char * operator *(StringA &str)
{
    struct Exception *exc = GetAnExceptionStructure();
    PRECONDITION((StrvalidA(str) && str.count > 0), exc);
    return &str.content[0];
}
```

This operator must always return a pointer type. It returns then, a pointer to the first character. This allows to support the *str = ‘a’ syntax. There are several differences though:

3 An empty string cannot be accessed. In traditional C it is possible to write *s = 'a', even if "s" is an empty string. This destroys the string, of course, it is no longer zero terminated, but no trap occurs at the point of the assignment since "s" points to valid memory. Traps occur later, when a non zero terminated string destroys the whole program. Here, any access to an empty string will provoke an exception.

4 The syntax *s++ is not supported. You can't increment a string structure. You can only increment a pointer to a string (a Stringp). Both types are distinct, to the contrary of traditional C where they are both the same.

5 You may wonder when you see that this operator returns a naked char pointer. Wouldn't this mean that this pointer could be misused in the code using the library? Happily for us, the compiler dereferences immediately the result of this operator, so the pointer can't be used anywhere else, or even be assigned to something. If you try to write "char *p = *s" it will provoke a compile time error since you are assigning a char to a pointer to char, what is not allowed.

Is it necessary to do this?

We could have decided that the user will always use the array notation (the [ ]), but in general, it is better to make the string package behave as much as possible (but not more) as traditional C strings. The objective is that people do not have to retrain themselves to use this package. As much as possible from the old syntax should be understood.

2.2.3.7 Imitating pointer addition

With traditional C strings it is valid to add an integer to a string pointer to obtain a pointer to the middle of the string. We can mimic this behavior by overloading the addition operator.

```
StringpA EXPORT operator+(StringA &s1,int n)
{
     StringpA result;
     struct Exception *exc = GetAnExceptionStructure();
     PRECONDITION((StrvalidA(s1) &&
        n >= 0 &&
        n < s1.count),exc);
     result.count = s1.count - n;
     result.content = s1.content + n;
     result.parent = &s1;
     return result;
}
```

We test for validity of the given string and check that the offset passed is correct. We return a Stringp (not a String!) that is initialized to point to the specified offset The result of this operation is to produce a fat pointer and not a String. This will cause problems, since even if the library tries to hide most differences, a Stringp is another kind of beast than a normal String. Note too that adding negative offsets is no longer possible.

2.2.3.8 String pointer operations

The library introduces the notion of string pointer structures, i.e. "fat" pointers that contain, besides the normal pointer to the contents, a count and a pointer to the parent string. Pointer operations on this structures are few, and they try to mimic the normal pointer behavior.

This pointers can be used as iterator objects to go through a portion or all the string contents.

You can obtain an iterator to the beginning of the string with:

```
String str = new_string(15);
Stringp pStr = begin(str);
```

The polymorphic function "begin" returns a pointer to the beginning of a sequential container.

The operations supported with string pointers are:

2.2.3.9 Pointer subtraction

```
int operator -(Stringp &s1, Stringp &s2)
{
    struct Exception *exc = GetAnExceptionStructure();
    PRECONDITION((Strvalidp(s1) && Strvalidp(s2) &&
      s1.parent == s2.parent), exc);
    return s1.content - s2.content;
}
```

The operator verifies that both pointers are valid, and that they point to the same string. The operation is more restricted than in traditional C since a subtraction operation is considered invalid if the pointers do not point to the same parent.

2.2.3.10 Addition of pointer and integer

This operation moves the given pointer forwards of backwards a specified number of characters.

```
Stringp operator+=(Stringp &s1,int n)
{
    struct Exception *exc = GetAnExceptionStructure();
    PRECONDITION((Strvalidp(s1) && n < s1.count),exc);
    s1.count -= n;
    s1.content += n;
    return s1;
}
```

2.2.3.11 Comparisons of a string pointer with zero

Several string functions return an invalid string pointer to indicate failure. It is practical that this pointer equals to NULL, so that code snippets like:

```
    if (!Strchr(String,'\n')) {
    }
```

work as intended. We overload the operator != and the operator == to mimic this behavior:

```
int operator != (const Stringp & string1, int i)
{
    if (isNullStringp(string1) && i == 0)
      return 0;
    return 1;
}
```

We allow only comparisons with zero. The operator == is very similar:

```
int operator == (const Stringp & string1, int i)
{
    if (i == 0 && isNullStringpA(string1))
      return 1;
    return 0;
}
```

2.2.4 String functions

The string library supports all the standard functions defined in string.h. The names chosen are the same, with the first letter in upper case: strcat is Strcat, strcmp is Strcmp, etc. Most of those functions are very simple, the specifications for the C run time library are quite primitive.

2.2.4.1 Comparing strings

Here is, for instance, the Strcmp function:

```
int overloaded Strcmp(String & s1, String & s2)
{
    struct Exception *exc = GetAnExceptionStructure();
    PRECONDITION(Strvalid(s1) && Strvalid(s2), exc);

    /* conversion widening the smaller to the wider string type */
    if (0 == s1.count && s2.count == 0){
      return 0;
    }
    if (0 == s1.count){
      return -1;
    }
    if (0 == s2.count){
      return 1;
    }
    int len = s1.count < s2.count ? s1.count : s2.count;
    return memcmp(s1.content, s2.content, len);
}
```

Strcmp accepts also a char *, so that users can write:

```
    if (!Strcmp(str,"Annie")) { ... }
```

This syntax is widespread, and it is important to support it. Here is a different version of Strcmp that accepts char pointers.

```
int overloaded Strcmp(String & string, const char* str)
{
    int len;
    struct Exception *exc = GetAnExceptionStructure();
    PRECONDITION((Strvalid(string) && (str != NULL)), exc);
    len = strlen(str);
    if (0 == string.count && len == 0) return 0;
    if (0 == string.count) return -1
    if (0 == len) return 1;
    len = len < string.count ? len, : string.count;
    return memcmp(string.content,str,len);
}
```

There are other variations, for supporting wide chars, and changing the order of the arguments.

2.2.4.2 Joining strings

To join several C strings into a single string the library proposes Strcatv[1]. It receives a series of strings, transforming them into a single String.

```
String Strcatv(char *s,...)
{
    int len = strlen(s);
    va_list ap,save;
    char *next,*p;
    StringA result;

    va_start(ap,s);
    save = ap;
    next = va_arg(ap,char *);
    while (next) {
```

1. This is essentially the same function as Str_catv from Dave Hanson's C Interfaces and implementations.

```
            len += strlen(next);
            next = va_arg(ap,char *);
        }
        va_start(ap,s);
        result = new_stringA(len);
        strcat(result.content,s);
        p = result.content + strlen(s);
        next = va_arg(ap,char *);
        while (next) {
            while (*next) {
                *p++ = *next++;
            }
            next = va_arg(ap,char *);
        }
        *p = 0;
        result.count = p - result.content;
        return result;
}
```

We make two passes over the strings, first collecting their lengths, then joining them. We avoid using strcat when joining the strings, since that would be very inefficient. The standard library strcat needs to find the terminating zero, what is more and more expensive as the length of the result string grows. Instead, we use a roving pointer that adds right at the end of the previous string the new one.

2.2.4.3 Accessing strings

The general accessing function for Strings is:

```
int operator[ ](String s,size_t index);
```

This operator returns the character at the given position. The operator checks that s is a valid string, and that the index is less than the length of the string.

```
int operator[](const String& string, size_t index)
{
        struct Exception *exc = GetAnExceptionStructure();
        PRECONDITION(Strvalid(string) && (index < string.count), exc);
        return string.content[index];
}
```

Single byte versions will use StrvalidA and receive StringA strings, double byte versions will use StringW and call StrvalidW. We will use the generic term String when we mean either StringW or StringA.

The operation indexed assignment (operator [ ] =) is handled by:[2]

```
int operator[]=(String & string, size_t index, int new_val)
{
        struct Exception *exc = GetAnExceptionStructure();
        PRECONDITION((Strvalid(string) && index < string.count), exc);

        string.content[index] = new_val;
        return new_val;
}
```

2.2.4.4 Adding and inserting characters

Inserting a single character is accomplished by the Strinsert function, or its alias "insert" that should work with all containers.

2. Note that in C++ is not possible to distinguish between this two. There is no [ ]= operator.

```
bool Strinsert(String &s,size_t pos,int newval)
{
     char *content;
     int new_capacity;
     struct Exception *exc = GetAnExceptionStructure();

     PRECONDITION(Strvalid(s), exc);
     PRECONDITION(pos < s.count,exc);

     new_capacity = calculate_new_capacity(s.capacity,s.capacity+1);
     if (new_capacity > s.capacity) {
        content = allocate_proper_space(new_capacity,SMALL);
        if (content == NULL)
           return true;
        memcpy(content,s.content,s.count);
        s.capacity = new_capacity;
        s.content = content;
     }
     else content = s.content;
     memmove(content+pos+1,content+pos,s.count-pos);
     s.count++;
     content[pos] = newval;
     content[s.count] = 0;
     return true;
}
```

The preconditions are a valid string and a valid index. We call the "calculate_new_capacity" function to get an estimate of the best new size if a string resize is needed. This is a relatively expensive operation, so we always allocate more space than strictly needed, to avoid resizing the string at each character added.

After we have ensured that we have the space needed, we make place for the new character by moving the tail of the string one position up.

The erase function (or Strerase) will remove a character from the string at the indicated position.

```
bool erase_string(String &s,size_t pos)
{
     int element_size;
     char *pcontents;
     wchar_t *pwcontents;
     if (!Strvalid(s))
        return false;
     if (s.count == 0)
        return false;
     struct Exception *exc = GetAnExceptionStructure();
     PRECONDITION(pos < s.count,exc);
     pcontents = s.content;
     if (pos == s.count-1) {
        pcontents[pos] = 0;
        s.count--;
        return true;
     }
     memmove(pcontents+pos,pcontents+pos+1,s.count-pos-1);
     s.count--;
     pcontents[s.count] = 0;
     return true;
}
```

We allow erasing characters from an empty string, and just return false if that is the case. This allows for loops that will use the result of Strerase to stop the iteration. In this case, we just return false.Otherwise we require a valid String and a valid index.

A small optimization is performed when the character to erase is the last character in the string. We spare us a memmove call by just setting the character to zero and decreasing the count field of the string structure. Otherwise, we have to move the characters from the position we are going to use one position down.

2.2.4.5 Mapping and filtering

A mapping operation in a string means applying a function to each character in the source string, and storing the result of that call in the new string that is the result of the operation.

```
String Strmap(String & from, int (*map_fun) (int))
{
    String result;
    struct Exception *exc = GetAnExceptionStructure();

    if (map_fun == NULL)
      return Strdup(from);
    PRECONDITION((Strvalid(from) && map_fun != NULL), exc);
    result = new_string(from.count);
    result.count = from.count;
    for (int i = 0; i < from.count; ++i){
      result.content[i] = map_fun(from.content[i]);
    }
    return result;
}
```

Note that a NULL function pointer means that the identity function[3] is assumed, and the whole operation becomes just a copy of the source string. We do not need to test for the validity of the source string in that case since Strdup does that for us.

We allocate a string that will contain at most so many characters as the source string including always a terminating zero. If the predicate function filters most of the characters, the string will be almost empty. Since we keep track of this in the capacity field of the String structure, this is less terrible than it looks like. The other solution would be to call twice the predicate function, but that would be very expensive in CPU usage.

A similar function is Strfilter, that will output into the result string only those characters that satisfy a boolean predicate function. Strfilter will accept either Strings or character strings. Here is the version that uses character strings:

```
String overloaded Strfilter(String & from, char *set)
{
    String result;
    int setlength;
    struct Exception *exc = GetAnExceptionStructure();

    PRECONDITION(Strvalid(from) && set != NULL, exc);
    setlength = strlen(set);
    result.content = allocate_proper_space(1+from.count,SMALL);
    if (result.content == NULL) {
      memset(&result,0,sizeof(result));
      return result;
```

3. The identity function in C is:
```
int identity(int c) { return c; }
```

```
        }
        result.capacity = 1+from.count;
        int j = 0;
        for(int i = 0; i < from.count; ++i) {
            for (int k=0; k<setlength;k++) {
                if (from.content[i] == set[k]) {
                    result.content[j++] =  set[k];
                    break;
                }
            }
        }
        result.count = j;
        return result;
    }
```

We need a valid string and a non-null set. We allocate space for the string including the terminating zero with the “allocate_proper_space” function. That function will raise an exception if no more memory is left and terminate the program. In case the user has overridden that behavior, we return an invalid String.

This is the single byte version, and we indicate this to “allocate-proper_space” with the SMALL parameter. For the wide character set we would replace that with WIDE.

If the allocation succeeds we set the capacity field, and we select the characters to be included in the result. At the end, we set the count field to the number of chars found that matched the predicate.

2.2.4.6 Conversions

To interact easily with other software we need to convert Strings in traditional strings, and we have to allow for converting traditional strings into the String structure. We use the overloaded cast operator to give the conversions the traditional C meaning.

```
    StringA operator()(char* cstr)
    {
        struct Exception *exc = GetAnExceptionStructure();
        StringA result;
        PRECONDITION(cstr != NULL,exc);
        result.count = strlen(cstr);
        result.capacity = calculate_new_capacity(0,1+result.count);
        result.content = allocate_proper_space(result.capacity,SMALL);
        if (result.content == NULL) {
            return invalid_stringA;
        }
        strcpy(result.content,cstr);
        return result;
    }
```

We build a new String structure from scratch. We require a valid C string, and calculate its length. We determine the best capacity for the new string, allocate the contents and copy.

We use this operator with a cast, for instance:

```
        void printName(String &s);
        ...
        printName((String)"Annie");
```

The inverse operator is the (much simpler) cast from a String to a char *.

```
    char *EXPORT operator()(StringA &str)
    {
        if (isNullStringA(str))
            return NULL;
        str.content[str.count] = 0;
        return str.content;
    }
```

We use this operator like this:

```
        String str;
        printf("%s\n",(char *)str);
```

Conversions from string pointers to char pointers is more difficult if we want to support pointers that span only a subset of the string. For instance if we have a pointer of length 2 that points to the third character of the string "This is it", the pointer points to the first 'i' and includes the 'i' and the 's' but not more. In that case we need to copy the contents before passing them to the calling function.

```
    char *EXPORT operator()(Stringp &strp)
    {
        char *result;

        result = strp.content;
        if (result[strp.count] == 0)
          return result;
        result = allocate_proper_space(strp.count+1,SMALL);
        if (result == NULL)
          return NULL;
        memcpy(result,strp.content,strp.count);
        return result;
    }
```

2.2.4.7 File operations

Files can be read as a whole into a string for later processing. This is a similar operation as building a memory mapped file.

```
    StringA EXPORT overloaded Strfromfile (char * file_name,int binarymode)
    {
        FILE *fp;
        StringA result;

        if (binarymode)
           fp = fopen(file_name, "rb");
         else
            fp = fopen(file_name, "r");
        if (NULL == fp){
          return invalid_stringA;
        }
        size_t needed = 0;
        int i_rval = 0;
        i_rval = fseek(fp, 0, SEEK_END);
        if (0 != i_rval) {
          fclose(fp);
          return invalid_stringA;
        }
        needed = ftell(fp);
        i_rval = fseek(fp, 0, SEEK_SET);
        if (0 != i_rval){
          fclose(fp);
          return invalid_stringA;
        }
        result.content = allocate_proper_space(needed+1,SMALL);
        if (result.content == NULL)
          return invalid_stringA;
        result.capacity = needed+1;
        size_t u_rval = fread(result.content, 1, needed, fp);
        fclose(fp);
        if (u_rval != needed){
            return invalid_stringA;
        }
        result.count = needed;
        return result;
}
```

According to the “binary mode” parameter, we read the file including the \r\n sequence into the contents or not. We determine the file size, then we read the string into the string contents.

Another often needed operation is reading a line from a string.

```
int Strfgets(StringA & source, int n, FILE *from)
{
        int i,val;
        if (StrvalidA(source) == 0 || n > source.capacity) {
            source.content = allocate_proper_space(n+1, SMALL);
            if (source.content == NULL)
                return 0;
            source.capacity = n+1;
        }

        for (i = 0; i < n; ) {
            val = fgetc(from);
            if (val == EOF || val == '\n')
                break;
            if (val != '\r') {
                source.content[i++] = val;
            }
        }
        source.content[i] = 0;
        source.count = i;
        return (i);
}
```

2.2.4.8 Reversing a String

Reversing the order of elements in a string is accomplished by our Strreverse or our reverse_string function. Both names lead to the same function.

```
bool reverse_string(String &s)
{
        if (!Strvalid(s))
            return false;
        char *p = s.content;
        char *q = p;
        int i = s.count;

        p += i;
        while (i-- > 0) {
            *q++ = *--p;
        }
        *q = 0;
        return true;
}
```

2.2.4.9 Searching text

The Strstr searches a pattern in a given string, and returns a fat pointer to a string (Stringp), or an invalid string if not found.

```
Stringp overloaded Strstr(String & string, String & find_this)
{
     char *strp,*end;
     int first_char,r;
     struct Exception *exc = GetAnExceptionStructure();

     PRECONDITION ((Strvalid(string) && Strvalid(find_this)), exc);
     first_char = find_this.content[0];
     strp = memchr(string.content,first_char,string.count);
     if (strp) {
        end = string.content + string.count;
        while (strp < end) {
           if (!memcmp(strp,find_this.content,find_this.count))
              return new_stringp(string,strp);
           else
              strp++;
        }
     }
     return invalid_stringp;
}
```

We search the first character of the string to search in the string. Each time we find it, we test if the search pattern is there. If yes we return a new string pointer, otherwise we go on until we reach the end of the string.

To search a character in a string we use the Strchr function:

```
Stringp overloaded Strchr(String & string, int element)
{
     struct Exception *exc = GetAnExceptionStructure();
     PRECONDITION((Strvalid(string)), exc);
     char *p = memchr(string.content,element,string.count);
     if (p){ // found
        return  new_stringp(string,p);
     }
     return invalid_stringp;
}
```

2.2.4.10 Making a string from a pipe

The function Strfrompipe will start a program and capture all its textual output into a String. This is useful for many GUI applications that want to show the results of a program in a different way, and many others.

The algorithm used is very simple: we start the command indicated in the string argument with the process using a redirected standard output into a temporary file. We read then this file into a string a return the result.

```
StringA overloaded Strfrompipe(String &Cmdline)
{
     STARTUPINFO startInfo;
     char *p;
     int processStarted,m;
     String result = invalidStringA;
     HANDLE hWritePipe;
     LPSECURITY_ATTRIBUTES lpsa=NULL;
     SECURITY_ATTRIBUTES sa;
     SECURITY_DESCRIPTOR sd;
```

```
ThreadParams tparams;
DWORD Status;
PROCESS_INFORMATION pi;
char *tmpfile = tmpnam(NULL);
char cmdline[1024];
char arguments[8192];

memset(cmdline,0,sizeof(cmdline));
memset(arguments,0,sizeof(arguments));
// Check for quoted file names with spaces in them.
if (Cmdline.content[0] == '"') {
     p = strchr(Cmdline.content+1,'"');
     if (p) {
          p++;
          strncpy(cmdline,Cmdline.content,p-Cmdline.content);
          cmdline[p-Cmdline.content] = 0;
          strncpy(arguments,p,sizeof(arguments)-1);
     }
     else return invalid_stringA;
}
else {
     strncpy(cmdline,Cmdline.content,sizeof(cmdline));
     p = strchr(cmdline,' ');
     if (p) {
          *p++ = 0;
          strcpy(arguments,Cmdline.content);
     }
     else arguments[0] = 0;
}
if (IsWindowsNT()) {
     InitializeSecurityDescriptor(&sd,
     SECURITY_DESCRIPTOR_REVISION);
     SetSecurityDescriptorDacl(&sd,TRUE,NULL,FALSE);
     sa.nLength = sizeof(SECURITY_ATTRIBUTES);
     sa.bInheritHandle = TRUE;
     sa.lpSecurityDescriptor = &sd;
     lpsa = &sa;
}
memset(&startInfo,0,sizeof(STARTUPINFO));
startInfo.cb = sizeof(STARTUPINFO);
tparams.file = fopen(tmpfile,"wb");
if (tparams.file == NULL) {
     return invalid_stringA;
}
hWritePipe = (HANDLE)_get_osfhandle(_fileno(tparams.file));
startInfo.dwFlags =STARTF_USESTDHANDLES|STARTF_USESHOWWINDOW;
startInfo.wShowWindow = SW_HIDE;
startInfo.hStdOutput = hWritePipe;
startInfo.hStdError = hWritePipe;
result = invalid_stringA;
processStarted = CreateProcess(cmdline,arguments,lpsa,lpsa,1,
            CREATE_NEW_PROCESS_GROUP|NORMAL_PRIORITY_CLASS,
            NULL,NULL,&startInfo,&pi);
if (processStarted) {
     WaitForSingleObject(pi.hProcess,INFINITE);
     GetExitCodeProcess(pi.hProcess,(unsigned long *)&Status);
     CloseHandle(pi.hProcess);
     CloseHandle(pi.hThread);
     m = 1;
}
```

```
        else m = 0;
        if (tparams.file)
             fclose(tparams.file);
        if (m) {
             result = Strfromfile(tmpfile,1);
        }
        remove(tmpfile);
        return(result);
}
```

2.2.4.11 Searching strings

There are several find functions. Here is an overview:

This functions perform primitive string searches. For more sophisticated searches use the reg-

Function	*Description*
`Strfind_first_of`	Finds the first character in a string that matches a given set. For instance using the set of the tab character and space, it finds the first whitespace character in a string.
`Strfind_last_of`	Finds the last character that matches the given set. Using the example above it would find the last white space character.
`Strfind_first_not_of`	Find the first char not in the given set.
`Strfind_last_not_of`	Find the last char not in the given set
`Strcspn`	Finds the index of the first char that matches any of the given set. The difference with Strfind_first_of is in the return value. Strcspn returns the length of the string in case of error, Strfind_first_of returns -1.
`Strchr`	Finds the first occurrence of a given character in a string.
`Strrchr`	Finds the last occurrence of a given character in a string.
`Strstr`	Finds the first occurrence of a pattern in a string.
`Strspn`	Finds the index of first char that doesn't match a character in a given set. The difference with Strfind_first_not_of is in the return value: Strspn returns the string length when no match is found instead of -1.

ular expression package or the perl regular expression package (pcre).

Finding the first whitespace character in a string:

```
Strfind_first_of(Source,"\t ");
```

Finding the end of the first word in a string:

```
char *alphabet =
"ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz";
Strfind_first_not_of(Source,alphabet);
```

Finding a word in a string:

```
String s = "A long short sentence";
```

```
Stringp ps = Strstr(s,"tence"); // Now ps points to "tence"
```

Note that Strstr returns a pointer structure, not a new string. You can convert the pointer into a string with the Strdup function.

2.2.4.12 Strfind_first_of

```
int overloaded Strfind_first_ofA(StringA &s,StringA &set)
{
        PRECONDITION(StrvalidA(s) && StrvalidA(set),exc);
        char *strcontents = s.content,*p;
        int i,j,count = s.count,setcount = set.count;
        int c;

        if (set.count == 0 || s.count == 0)
                return -1;
        for (i=0; i<count;i++) {
                p = set.content;
                c = strcontents[i];
                for (j=0; j<setcount;j++) {
                        if (c == p[j])
                                return i;
                }
        }
        return -1;
}
```

2.2.4.13 Joining strings

To join a string to another there are several functions described below. Note that the operator '+' is not used for joining strings. The reasoning behind this is that the addition of strings in the sense used here is non-commutative. "abc" + "dce" give "abcdce" but "dce"+"abc" gives "dceabc", what is quite different. An overloading of the + operation is not warranted. Strings are not numbers, and if we did this overloading, we could come to the interesting conclusion that `"1"+"1" = "11"`...

Function	*Description*
`Strcat`	Joins two strings, changing the first.
`Strncat`	Joins up to n characters from the second argument to the first.
`Strchcat`	Inserts a character at the end of the string.
`Strcatv`	Joins several C strings into a single String.

Given the string

```
S1 = "abcde";
```

The call

```
Strcat(S1,"fgh");
```

will modify the contents of S1, that will after the call contain "abcdefgh". It is possible that no resize operation is necessary, if the capacity of S1 was already big enough to accomodate both strings. Otherwise the library resizes S1.

Resizing operations are expensive when done frequently. To avoid them, it is better to resize the string before doing the joining in such a way that the resize operation is done once, instead of several times.

2.2.4.14 Strncat

```
bool EXPORT overloaded StrncatA(StringA & to,StringA & from,size_t
elements_to_cat)
{
        if (!StrvalidA(to)){
                if (StrvalidA(from)) {
                        to.count = from.count;
                        to.capacity = from.capacity;
                        to.content = GC_malloc(from.capacity);
                        memcpy(to.content,from.content,from.count);
                        return true;
                }
                return false;
        }
        PRECONDITION((StrvalidA(from)), exc);
        size_t needed_space = elements_to_cat + to.count+1;
        to = str_newA(needed_space, to);
        strncat(to.content, from.content, elements_to_cat);
        to.count = needed_space-1;
        to.content[to.count] = 0;
        return true;
}
```

2.2.4.15 Strcat

This just builds a string from the “from” argument and calls Strncat.

```
bool EXPORT overloaded StrcatA(StringA &to, char* from)
{
        StringA s;

        if (from == NULL)
                return true;
        s.count = strlen(from);
        s.capacity = s.count+1;
        s.content = from;
        return Strncat(to, s, s.count);
}
```

2.2.4.16 Strmap

This function applies a function in sequence to all characters in a string. It is useful for implementing filters or other transformations to a given string. For instance if we want to change all characters of a string into upper case, we can do the following:

```
#include <strings.h>
#include <ctype.h>
int change(int c)
{
        if (islower(c))
                c = toupper(c);
        return c;
}
```

```
int main(int argc,char *argv[])
{
        String s,s1;
        for (int i=0; i<argc;i++) {
                s = argv[i];
                s1 = Strmap(s,change);
                printf("%s\n",(char *)s1);
        }
        return 0;
}
```

This program will output its arguments transformed in uppercase. This is an example, of course. There is already a function that does that: Strcmpi.

2.2.4.17 Filters

The Strfilter function builds a new string with the characters that fulfill a predicate function passed to it as an argument or is a member of a given set. For instance, if you want to extract all numeric data from a string that contains numbers and other data you use:

```
bool isnumeric(int c)
{
     return  c >= '0' && c <= '9';
}
String s1 = "Subject age is 45 years";
String s2 = Strfilter(s1,isnumeric); // Now s2 is "45"
```

Strfilter will also accept a String or char/wide character string. This means that only characters will be output in the result string that match some character in the given set. For instance:

```
String s1 = "Subject age is 45 years";
String s2 = Strfilter(s1,"0123456789"); // Now s2 is "45"
```

Obviously, this function accepts also two Strings as arguments.

2.3 Strings in other languages

Strings are a very common, I would say almost universal data type. Here is a comparison with the interface provided by other languages.

Language	*Implementation*

C++	The C++ strings package is very similar to the one proposed here. I used a similar interface on purpose: Avoid gratuitous incompatibilities with C++. Of course, essential differences remain. in C there are no constructors, destructors, templates etc.
	C++ accepts many initializers forms: you can write
	`string mystring("Initial content");`
	`string mystring = "Initial_content");`
	`string s2 = s1(mystring,0,1); // s2 is then "I"`
	Other operations are supported like append, insert, erase, replace, etc. They all use the C++ function table in each object:
	`s2 = "ABC";`
	`s2.append("abc"); // Now s2 is "ABCabc"`
	The same operation in C is:
	`append(s2,"abc");`

Language	*Implementation*

Common Lisp	Lisp has a “string” data type, that is defined as a specialized vector of charac-ters. Accessing an element is done with:
	`(char "Abcd" 1) ==> "b"`
	Comparison is done with
	`(string= string1 string2)`
	There are other optional arguments to indicate a starting and ending point for the comparison. The result is either true (strings equal, or false, different). For lexicographical comparisons there are the functions `string<`, etc.
	To modify a character in a string you use:
	`(setf (char "Abcd" 1) #\1) ==> "1bcd"`

APL	Apl is a language where vectors are the main data type, in contrast to Lisp, where lists are paramount. APL strings are just vectors like all others. The rich primitive operations of APL in vectors can be applied to strings. For instance if A and B are strings of equal length `A = B` will yield a boolean vector of equal length to A, filled with one or zeroes if the corresponding character positions match.

Ruby	Ruby strings can contain characters or just binary data, as our strings. There is an elaborate escaping mechanism to specify numerical values within strings. Embedded commands within strings allow specifications like:
	`"{‘Ho! ‘*3}Merry Christmas" ==>`
	`"Ho! Ho! Ho! Merry Christmas"`
	Search expressions are very sophisticated, including regular expressions. There are more than 75 methods for the string library. Here is for instance the “slice” method:
	`a = "hello there"`
	`a.slice(1)       ==> 101`
	`a.slice(1,3)     ==> "ell"`
	`a.slice(1..3)    ==> "ell"`
	`a.slice(-4..-2)  ==> "her"`
	Note that slicing a string with only one index produces an integer, in this case the ASCII value of ‘h’.

C#	C sharp has a class string, with a similar implementation as the strings described above. C# strings are read only. If you want to modify them you have to use similar classes like “Buffer”. Normally you just make a new string when you modify some part of it.

Language	*Implementation*

ADA	Ada supports three kinds of strings:
	1) Fixed length. This length mustn't be known at compile time, it can be the result of a run-time calculation.
	2) Bounded length. It can be used when the maximum length of a string is known and/or restricted. This is often the case in database applications where only a limited amount of characters can be stored. Like with Fixed-Length Strings the maximum length does not need to be known at compile time.
	3) Unbounded length.
	Here is an example of this type of strings in ADA:
	`with Ada.Text_IO;`
	`with Ada.Command_Line;`
	`with Ada.Strings.Unbounded;`
	
	`procedure Show_Commandline is`
	
	`   package T_IO renames Ada.Text_IO;`
	`   package CL   renames Ada.Command_Line;`
	`   package SU   renames Ada.Strings.Unbounded;`
	
	`   X :  SU.Unbounded_String`
	`     := SU.To_Unbounded_String (CL.Argument (1));`
	
	`begin`
	`   T_IO.Put ("Argument 1 = ");`
	`   T_IO.Put_Line (SU.To_String (X));`
	
	`   X := SU.To_Unbounded_String (CL.Argument (2));`
	
	`   T_IO.Put ("Argument 2 = ");`
	`   T_IO.Put_Line (SU.To_String (X));`
	`end Show_Commandline;`

2.4 String collections

After we had finished the strings library, we developed the string collection package. A string collection is a table of strings that will grow automatically when you add elements to it. It has a completely different interface as the strings library, using the popular

```
string.function
```

notation like in the C# language or in C++.

It uses an interface, i.e. a table of functions to provide the functionality and data access a string collection needs. Since the names of the functions are enclosed within the interface structure we can use mnemonic names like "Add", etc, without fear of messing with the user name space, and without adding lengthy prefixes.

Other advantage of an interface are the extensibility of it. You can add functions of your own to the interface without interfering with the existing ones. We will discuss this later when we discuss subclassing, but it is obvious that you can define a new interface that has the first members as the given interface, but it has some extra members of your own.

2.4.1 The interface

We define first an empty structure, that will be fully defined later, to be able to define the functions in our interface

```
typedef struct _StringCollection StringCollection;
```

With his behind us, we can now define the interface:[4]

```
typedef struct {
        // Returns the number of elements stored
        int (*GetCount)(StringCollection &SC);

        // Is this collection read only?
        int (*IsReadOnly)(StringCollection &SC);

        // Sets or unsets this collection's read-only flag
        int (*SetReadOnly)(StringCollection &SC,int flag);

        // Adds one element at the end. Given string is copied
        int (*Add)(StringCollection &SC,char *newval);

        // Adds a NULL terminated table of strings
        int (*AddRange)(StringCollection &SC,char **newvalues);

        // Clears all data and frees the memory
        int (*Clear)(StringCollection &SC);

        //Case sensitive search of a character string in the data
        bool (*Contains)(StringCollection &SC,char *str);

        // Copies all strings into a NULL terminated vector
        char **(*CopyTo)(StringCollection &SC);

        //Returns the index of the given string or -1 if not found
        int (*IndexOf)(StringCollection &SC,char *SearchedString);

        // Inserts a string at the position zero.
        int (*Insert)(StringCollection &SC,char *);

        // Inserts a string at the given position
        int (*InsertAt)(StringCollection &SC,int idx,char *newval);

        // Returns the string at the given position
        char *(*IndexAt)(StringCollection &SC,int idx);

        // Removes the given string if found
        int (*Remove)(StringCollection &SC,char *);

        //Removes the string at the indicated position
        int (*RemoveAt)(StringCollection &SC,int idx);
```

4. Note that the interface uses extensively references, as here indicated by StringCollection &SC. This means that the argument must be a string collection object or a reference to it. This extension of lcc-win32 allows us to avoid many test for a NULL pointer, and at the same time retain the efficiency of passing structure arguments using pointers insted of copying the value. To make this code work with a compiler that doesn't support references just eliminate the "&" and pass the structure by value. This will be discussed in more detail in the "Portability" section below.

```
            // Frees the memory used by the collection
            int (*Finalize)(StringCollection &SC);

            // Returns the current capacity of the collection
            int (*GetCapacity)(StringCollection &SC);

            // Sets the capacity if there are no items in the collection
            int (*SetCapacity)(StringCollection &SC,int newCapacity);

            // Calls the given function for all strings.
            // "Arg" is a used supplied argument
            // that can be NULL that is passed to the function to call
            void (*Apply)(StringCollection &SC,
                          int (*Applyfn)(char *,void * arg),void *arg);

            // Calls the given function for each string and saves all
            // results in an integer vector
            int *(*Map)(StringCollection &SC,int (*Applyfn)(char *));

            // Pushes a string, using the collection as a stack
            int (*Push)(StringCollection &SC,char *str);

            // Pops the last string off the collection
            char * (*Pop)(StringCollection &SC);

            // Replaces the character string at the given position with
            // a new one
            char *(*ReplaceAt)(StringCollection &SC,int idx,char *val);

            // Returns whether the collection makes case sensitive
            // comparisons or not
            int (*IsCaseSensitive)(StringCollection &SC);

            // Sets case sensitivity by comparisons
            int (*SetCaseSensitive)(StringCollection &SC,int newval);

            // Compares two string collections
            bool (*Equal)(StringCollection &SC1,StringCollection &SC2);
    } StringCollectionInterface;
```

Note that this lengthy structure is not replicated at each string collection object. Each string collection holds just a pointer to it, spending only sizeof(void *) bytes.

Once the interface is defined, the rest is quite simple:

```
    // Definition of the String Collection type
    struct _StringCollection {
         StringCollectionInterface *lpVtbl; // The table of functions
            size_t count;            /* in element size units */
            char **contents;         /* The contents of the collection */
            size_t capacity;         /* in element_size units */
         unsigned int flags;         // Read-only or other flags
    };
```

Each string collection will have a pointer to the interface. This uses a few bytes for the pointer, but I think this is RAM well spent. Besides, any medium size collection will hold a lot of data anyway, so the space used by the pointer is not significant at all.

The only exported function of this library is of course the creation function:

```
    StringCollection * newStringCollection(int startsize=0);
```

The creation function allocates and initializes the data structure, setting a pointer to the interface function table.

2.4.2 Memory management

The easiest way to use the string collection is to use it with the garbage collector. The collection copies all the data it receives, but when indexing a collection you receive not a copy but the data itself. You have to remember to call the "Finalize" function to free the memory allocated by the collection when you are finished with it. And you should not free a string from the collection since this will provoke a trap. To avoid all this problems, just use it with the GC.

It could be argued that a simpler interface would have been to make a copy of the string that the user receives each time we access the collection but then, it would be necessary for you to free the strings received from the collection, what makes the usage of the library in a DLL that is called from another compiler runtime impossible.

2.4.3 Using the library

There is a problem however. To call one of those functions, for instance "Add", to add a string to the collection we will have to write:

```
SC = newStringCollection(25);
SC->lpVtbl->Add(SC,"This is a string to be added");
```

Lcc-win32 has developed a shorthand notation for this, that allows you to write:

```
SC->Add("This is a string to be added");
```

This is even more pronounced when indexing the string collection:

```
char *p = SC->lpVtbl->IndexAt(SC,5);
```

instead of

```
char *p = SC[5];
```

The algorithm used by the compiler is very simple. When dereferencing a structure, if the field indicated (in this case "Add") does NOT exist, the compiler looks at the first position for a function table called "lpVtbl". If this field exists, and it has a function called with the same name the user wrote (in this case, we know, it is the name "Add"), and this function pointer has as its first argument a pointer to the structure we are dereferencing, the compiler supplies the call as if the user had written the full syntax.

Here is a small sample program that demonstrates what you can do with this library:

```
#include <containers.h>
static void PrintStringCollection(StringCollection SC)
{
        printf("Count %d, Capacity %d\n",SC.count,SC.capacity);
        for (int i=0; i<SC.GetCount();i++) {
                printf("%s\n",SC[i]);
        }
        printf("\n");
}
int main(void)
{
        StringCollection SC = newStringCollection();
        char *p;
        SC.Add("Martin");
        SC.Insert("Jakob");
        printf("Count should be 2, is %d\n",SC->GetCount());
        PrintStringCollection(SC);
```

```
                SC.InsertAt(1,"Position 1");
                SC.InsertAt(2,"Position 2");
                PrintStringCollection(SC);
                SC.Remove("Jakob");
                PrintStringCollection(SC);
                SC.Push("pushed");
                PrintStringCollection(SC);
                SC.Pop();
                PrintStringCollection(SC);
                p = SC[1];
                printf("Item position 1:%s\n",p);
                PrintStringCollection(SC);
        }
```

2.4.4 Implementation

2.4.4.1 Creating a string collection.

```
        StringCollection  newStringCollection(int startsize=0)
        {
                StringCollection result;

                memset(&result,0,sizeof(StringCollection));
                result.lpVtbl = &lpVtableSC;
                if (startsize > 0) {
                        result.contents = MALLOC(startsize*sizeof(char *));
                        if (result.contents == NULL) {
                              ContainerRaiseError(CONTAINER_ERROR_NOMEMORY);
                        }
                        else {
                                memset(result.contents,0,
                                           sizeof(char *)*startsize);
                                result.capacity = startsize;
                        }
                }
                return result;
        }
```

We allocate memory for the string collection structure, then for the data, and we set the capacity to the initial size. Since lcc-win32 supports functions with default arguments, we can suppose that a length of zero means the parameter wasn't there, and we use the default value. In another environments/compilers, the same convention can be used, but the argument must be there.

We are immediately confronted with the first design decision. What happens if we do not get the memory needed?

Many actions are possible:

1: Throw an exception. This can be catched with a __try/__except construct, and is a natural solution for exceptional conditions, in this case, there is no more available RAM.
2: Print an error message and abort the program. This is decision with too many consequences for the user, and gives him/her no chance to correct anything.
3: Return NULL. If there isn't any test in user code for a wrong return value, the program will crash the first time the user wants to use the collection. This is better than crashing in a library function, and such an error can be easily spotted in most cases. The problem with this is the complicated user interface. To catch all errors, a program must test for NULL reports at many places, what many people will not do.

4: Make all functions return a code indicating success or failure. The result would be stored in a pointer passed to the function, and no direct result would be available. This solution is implemented for example in Microsoft's strsafe functions.

In the first versions of the library, I had adopted solution 3: return NULL, no exceptions. But as the library code was developed, the testing for NULL became more and more cumbersome, and the code of the library grew with each NULL test. I decided then to adopt solution one, and throw an exception whenever abasic premise of the program wasn't satisfied: a patently wrong argument, and no more memory. I avoided throwing exceptions for errors that weren'ty critical, for instance trying to modify a read only container.

Note the usage of the FREE macro. We leave the user the choice of compiling the library with the GC or without it. If the macro NO_GC is defined, we avoid the garbage collector and use the malloc/free system.

We assign the table of functions field (`lpVtbl`) the address of a static function table defined in the module. Note that the function table can be in principle be modified by the user, by replacing one or more functions with other functions more adapted to his/her needs. This "sub-classing" could be added later to the interface of the string collection library.

We have then in the header file:

```
typedef struct {
     int (*GetCount)(StringCollection &SC);
     //... and the prototypes of all other
     // interface functions go here
} StringCollectionInterface;
```

In our implementation file we define a master table like this:

```
static StringCollectionInterface lpVtableSC = {
     GetCount, IsReadOnly, SetReadOnly, Add,
     AddRange, Clear, Contains, CopyTo, IndexOf,
     Insert, InsertAt, IndexAt, Remove, RemoveAt,
     Finalize, GetCapacity, SetCapacity, Apply,
     Map, Push, Pop, ReplaceAt,IsCaseSensitive,SetCaseSensitive,
};
```

At each call of our constructor procedure we assign to the lpVtbl item this master table. Note that we do not copy the contents of the table, each StringCollection has a pointer to the original table. This allows for interesting side effects, as we will see later.

2.4.4.2 Adding items to the collection

This function returns the number of items in the collection after the addition, or a value less or equal to zero if there was an error.

```
static int Add(StringCollection &SC,char *newval)
{
        if (SC.flags & SC_READONLY)
                return -1;
        if (SC.count >= SC.capacity) {
                if (!Resize(SC))
                        return 0;
        }

        if (newval) {
                SC.contents[SC.count] = DuplicateString(newval);
                if (SC.contents[SC.count] == NULL) {
                        return 0;
                }
        }
```

```
		else
			SC.contents[SC.count] = NULL;
		SC.count++;
		return SC.count;
	}
```

The library supports a “Read only” flag, that allows the user to build a collection and then protect it from accidental change. In the case that the flag is set we do not touch the collection and return a negative value to indicate failure.

If the collection is full, we try to resize it. If that fails, the result is zero and we exit. More about this below, but before continuing let’s see this a bit nearer

If the resizing succeeded or there was enough place in the first place, we go on and store the new element. Since the user could store a NULL value, we test for it, and avoid trying to duplicate a null pointer. Note that we always duplicate the given string before storing it

The function that resizes the collection is straightforward:

```
	static int Resize(struct _StringCollection &SC)
	{
		int newcapacity = SC.capacity + CHUNKSIZE;
		char **oldcontents = SC.contents;
		SC.contents = MALLOC(newcapacity*sizeof(char *));
		if (SC.contents == NULL) {
			SC.contents = oldcontents;
			ContainerRaiseError(CONTAINER_ERROR_NOMEMORY);
			return 0;
		}
		memset(SC.contents,0,sizeof(char *)*newcapacity);
		memcpy(SC.contents,oldcontents,SC.count*sizeof(char *));
		SC.capacity = newcapacity;
		FREE(oldcontents);
		return 1;
	}
```

The algorithm here is just an example of what could be done. Obviously, if you resize very often the collection, the overhead of this is considerable. The new fields are zeroed[5], and the old contents are discarded.

2.4.4.3 Adding several strings at once

You can pass an array of string pointers to the collection, finished by a NULL pointer. The collection adds the strings at the end.

```
	static int AddRange(struct _StringCollection & SC,char **data)
	{
		int i = 0;
		if (SC.flags & SC_READONLY)
			return 0;
		while (data[i] != NULL) {
			int r = Add(SC,data[i]);
			if (r <= 0)
				return r;
			i++;
		}
		return SC.count;
	}
```

5. You see how this operation could be done faster? Look at the code again. Do we zero only the new fields?

We use the Add function for this, iterating through the input string array. Note that any error stops the operation with some strings added, and others not. This could be done differently, making a “roll back” before returning, so that the user could be sure that either all strings were added, or none. To keep the code simple however, it is better to leave this “as is”.

2.4.4.4 Removing strings from the collection

RemoveAt returns the number of items in the collection or a negative value if an error occurs.

```
static int RemoveAt(struct _StringCollection &SC,int idx)
{
        if (idx >= SC.count || idx < 0 || (SC->flags & SC_READONLY))
                return -1;
        if (SC.count == 0)
                return -2;
        FREE(SC.contents[idx]);
        if (idx < (SC.count-1)) {
                memmove(SC.contents+idx,SC.contents+idx+1,
                        (SC.count-idx)*sizeof(char *));
        }
        SC.contents[SC.count-1]=NULL;
        SC.count--;
        return SC.count;
}
```

We start by taking care of the different error conditions. Note that to simplify things several errors return the same result. A more detailed error reporting is quite trivial however.

If we are not removing the last item in the collection, we should move all items beyond the one we are removing down towards the origin. This is done with memset.

We do not free the memory used by the pointer array, only the memory used by the string that we just remove. This could be a problem for a collection that grows to a huge size, then it is emptied one by one. We could add logic here that would check if the capacity of the collection relative to the used space is too big, and resize the collection.[6]

A question of style is important here. Note that the code above *could* have been written like this:

```
        SC.contents[--SC.count]=NULL;
        return SC.count;
```

instead of

```
        SC.contents[SC.count-1]=NULL;
        SC.count--;
        return SC.count;
```

We avoid a subtraction of one with the first form. But I think the second form is much clearer...

2.4.4.5 Retrieving elements

To get a string at a given position we use IndexAt.

```
static char *IndexAt(struct _StringCollection &SC,int idx)
{
        if (idx >=SC.count || idx < 0)
```

6. Is it really necessary to set the pointer to NULL? Strictly speaking not, since the collection should never access an element beyond the count of elements. In a garbage collection environment however, setting the pointer to NULL erases any references to the string and allows the garbage collector to collect that memory at the next GC.

```
                return NULL;
        return SC.contents[idx];
}
```

What to do when we receive a bad index? This is a similar problem to memory exhaustion. Something needs to be done, maybe even more so than in the case of lack of memory. This is a hard error in the program. You can modify the code here to change the library, but keeping in line with the behavior of the library in other places, we just return NULL.

This is not a very good solution since the user could have stored NULL in the collection, at would be mislead into thinking that all went well when in fact this is not the case.

Since lcc-win32 allows operator overloading, we can use it to easy the access to the members of the collection:

```
char *operator[](StringCollection SC,int idx)
{
        return IndexAt(SC,idx);
}
```

We can now use the string collection as what it is: a table of strings

2.4.4.6 Finding a string

The function IndexOf will return the index of a string in the collection or a negative value if the string is not found.

```
static int IndexOf(struct _StringCollection &SC,char *str)
{
        int i;
        int (*cmpfn)(char *,char *);

        if (SC.flags & SC_IGNORECASE) {
                cmpfn = stricmp;
        }
        else cmpfn = strcmp;

        for (i=0; i<SC.count;i++) {
                if (!cmpfn(SC.contents[i],str)) {
                        return i;
                }
        }
        return -1;
}
```

To avoid testing at each step in the loop if the comparison will be case insensitive or not, we assign the function to use to a function pointer before the loop starts.

2.4.4.7 Conclusion

These are the most important functions in the library. There are several others, and you can look at the code distributed with the lccwin32 distribution for the complete source. The documentation will tell you exactly what each function is supposed to do, and the different return values of each function. The source code will be installed in

\lcc\src\stringlib

It comes with a makefile, so if you have lcc in the path, you just need to type “make” to build the library.

2.5 Generalizing the string collection

We have now a general framework for handling string collections. Looking at the code, it is easy to see that with a little effort, we could make this much more general if we would replace the strings with a fixed size object, that can be any data structure. This general container is present in other languages like C#, where it is called “ArrayList”. You can store in an ArrayList anything, in C# it is not even required that the objects stored inside should be of the same type.

Since the nature of the objects stored is not known to the container, it is necessary to cast the result of an ArrayList into the final type that the user knows it is in there. In C# this is the “object”, the root of the object hierarchy, in C it is the void pointer, a pointer that can point to any kind of object.

If we look at the code of one of the string collection functions we can see the following:

```
static char *IndexAt(struct _StringCollection &SC,int idx)
{
        if (idx >=SC.count || idx < 0)
                return NULL;
        return SC.contents[idx];
}
```

We can easily generalize this to a container by changing the char pointer declaration to just void pointer!

Slightly more difficult is the Add function. The code of it in our string collection looked like this:

```
static int Add(StringCollection &SC,char *newval)
{
        if (SC.flags & SC_READONLY)
                return -1;
        if (SC.count >= SC.capacity) {
                if (!Resize(SC))
                        return 0;
        }

        if (newval) {
                SC.contents[SC.count] = DuplicateString(newval);
                if (SC.contents[SC.count] == NULL) {
                        return 0;
                }
        }
        else
                SC.contents[SC.count] = NULL;
        SC.count++;
        return SC.count;
}
```

We see that there are only two places where we have character string specific code: In the type declaration and in the call to the `DuplicateString` procedure. The first is easy to fix, but the seconds needs a little bit more reflection. DuplicateString doesn’t needs to know how many bytes to copy because it uses the terminating zero of the string to stop. When generalizing to a general data structure we can’t count with the absence of embedded zeroes in the data, so we have to give the size of the object explicitly.

If we decide to store only one type of object into our containers, we could store the size in the container structure at creation time, and then use it within our code.

The code of our `Add` function for flexible arrays would look like this:

```
static int Add(StringCollection &AL,void *newval)
{
        if (AL.flags & SC_READONLY)
                return -1;
        if (AL.count >= AL.capacity) {
                if (!Resize(AL))
                        return 0;
        }

        if (newval) {
                AL.contents[AL.count] =
                        DuplicateElement(newval,AL.ElementSize);
                if (AL.contents[AL.count] == NULL) {
                        return 0;
                }
        }
        else
                AL.contents[AL.count] = NULL;
        AL.count++;
        return AL.count;
}
```

This is almost the same code but now, we use the extra field in the container structure to indicate to `DuplicateElement` how big is the object being stored. Obviously, `DuplicateElement` will use memcpy and not `strcpy` to copy the contents, but besides this minor change the code is the same.

The interface of the creation function must be changed also. We need an extra parameter to indicate it how big will be the objects stored in the flexible array. The interface for the creation function looks now like this:

```
ArrayList * newArrayList(size_t elementsize,int startsize=0);
```

The first argument is required and not optional: we must know the size of each element. The ArrayList structure will have a new field (ElementSize) to store the size that each object will have.

The change to other functions is trivial. Here is the code for the `Contains` function:

```
static int Contains(ArrayList &AL,void *str)
{
        int c;
        if (str == NULL)
                return 0;
        for (int i = 0; i<AL.count;i++) {
                if (!memcmp(AL.contents[i],str,AL.ElementSize))
                        return 1;
        }
        return 0;
}
```

The code for the Contains function for a string collection is:

```
static int Contains(struct _StringCollection & SC,char *str)
{
        int c;
        int (*cmpfn)(char *,char *);
        if (str == NULL)
                return 0;
        c = *str;
        if ((SC.flags & SC_IGNORECASE) == 0) {
                cmpfn = strcmp;
        }
        else {
                cmpfn = stricmp;
        }
        for (int i = 0; i<SC.count;i++) {
                if (!cmpfn(SC.contents[i],str))
                        return 1;
        }
        }
        return 0;
}
```

Since we use memcmp, there is no sense to worry about case sensitivity. Besides that, only one line needs to be changed.

Note that we make a *shallow* comparison: if our structure contains pointers we do not compare their contents, just the pointer value will be compared. If our structure contains pointers to strings for example they will compare differently even if both pointers contain the same character sequence.

What is interesting too is that we use the same names for the same functionality. Since the function names are in their own name space, we can keep mnemonic names like Add, Contains, etc.

2.5.1 Subclassing

Let's suppose you have a structure like this:

```
typedef struct {
     int HashCode;
     char *String;
} StringWithHash;
```

You would like to change the code of the IndexOf function so that it uses the hash code instead of blindly making a memcmp.

This is possible by rewriting the function table with your own pointer, say, HashedIndexOf.

```
static int HashedIndexOf(ArrayList &AL,void *str)
{
        int i,h,top;
        StringWithHash *src=(StringWithHash *)str,*elem;

        h = src->HashCode;
        top = AL->GetCount();
        for (i=0; i<top;i++) {
                elem = (StringWithHash *)AL[i];
                if (elem->HashCode == h &&
                      !strcmp(elem->String,src->String))
                        return i;
                }
        }
        return -1;
}
```

Before doing the strcmp, this function checks the hash code of the string. It will only call strcmp if the hash code is equal. This is an optimization that can save a lot of time if the list of strings is long. Note that *we kept the interface of the function identical* to IndexOf. That is very important if we want this to work at all.

You can set this function instead of the provided IndexOf function just with:

```
StringWithHash hStr;
// The structure is allocated, hash code calculated, etc.
// We allocate a 8000 long ArrayList and fill it in
ArrayList *AL = newArrayList(sizeof(StringWithHash,8000);
// Code for the fill-in omitted
// Now we set our function at the right place
AL->lpVtbl->IndexOf = HashedIndexOf;
```

Done.

There is an important point to remember however. If you look at the creation code of the newArrayList function, you will see that the lpVtbl structure member is just a pointer to a static table of functions. By doing this you have made *all* ArrayLists use the new function, even those that do not hold StringWithHash structures. You have modified the master copy of the function table. This may be what you want, probably it is not.

A safer way of doing this is to copy first the lpVtbl structure into a freshly allocated chunk of memory and then assigning the function pointer.

```
// Allocate a new function table.
ArrayListFunctions *newFns =
         GC_malloc(sizeof(ArrayListFunctions));
// Copy the master function table to the new one
memcpy(newFns,AL->lpVtbl,sizeof(ArrayListFunctions));
// Assign the new function in the copied table
newfns->IndexOf = HashedIndexOf;
//Assign this new table to this array list only
AL->lpVtbl = newFns;
```

This way, you modify only this particular ArrayList to use the function you want. Note that there is no freeing of the allocated memory since we used the memory manager. If you use malloc you should free the memory when done with it.

This subclassing is done automatically in other languages, but following specified rules. Here we are in C, you are on your own. This allows you much more flexibility since it is you that writes the rules how the subclassing is going to happen, but introduces more opportunities for making errors.

This method of replacing the default functions with your own will work of course with all structures having a function table, like the StringCollection.

2.5.1.1 Drawbacks

All this is nice but we have no longer compiler support. If we initialize an ArrayList with the wrong size or give an ArrayList the wrong object there is no way to know this until our program crashes, or even worst, until it gives incorrect results. We have used everywhere a void pointer, i.e. a pointer that can’t be checked at all by the compiler.

2.6 Lists

Lists are a very popular data structure. You make one before you go to the supermarket, a list of things you need.. A list is a series of items that can have any length and that is normally represented by a series of items in memory, joined by pointers from the first to the last (single linked lists).

We can describe this structure in C like this:

```
struct listElement {
     void * PointerToData;
     struct list Element *PointerToNextItem;
};
```

We have a first pointer that indicates just where the data item resides in memory, and another one, telling us where the next item can be found. It is customary to end the list by setting this pointer to a NULL value.

Going from the first item (the root of the data structure) to the last implies assigning a moving pointer to the first element, then following the “Next” pointers till we hit NULL.

```
struct listElement *p = Root;
while (p != NULL) {
     p =  p->PointerToNextItem;
}
```

In single linked lists there is only one possible direction: forward. We can only start at the root and go to the last. To find the item “just before this one” we have to start again at the root and search forward until we find an item whose “Next” pointer points to this item.

This drawbacks can be solved with double linked lists, where we store two pointers, forward, and backward, each pointing to the next item and the previous item. This allows us to move from one item to the previous or next one, but comes at a price: for each data item we have now an overhead of two pointers and the pointer to the data, i.e. three pointers for each data item.

If the size of the item to be stored is smaller than the size of a pointer, we could optimize ans save us an unneeded pointer by storing the data directly in the pointer slot.

Single linked lists are the simplest to begin with. We will design an interface for them, in the style of the interfaces of the string collection or the “Array list” containers. The interface will be very similar since the lists are also linear containers, there is a natural concept of order, or sequence, in them. It makes sense then, to use the array index operator to access this items, and to use the same names as we developed for the string collection and the ArrayList containers: Add, Insert, Remove, etc.

Of course there are fields that make no sense with lists. There is no need for a “Capacity” field, since we can store in a list as many items as we like, provided we do not ask for more items than our virtual memory system can hold. In modern machines this means an almost unlimited supply of items...

The same operations like “Pop” and “Push” will be implemented differently than in arrays. In the ArrayList structure, a Push operations adds an item at the higher indexes of the array, since the cost of getting to the last item is the same as the cost of getting into any other item. With lists, getting to the last element can be an expensive operation, so we just add items at the first position and pop items from the first position. Adding items to the first position is very easy in lists, since we do not have to copy all items one place up as we would have to do with arrays.

The same as in the ArrayList structure we have now to decide if we want to store items of any type or just items of a single type. We decide for the later for “compatibility reasons”[7]

We build for each list a small (as small as possible) header, containing information about this list.

```
struct _List {
        ListFunctions *lpVtbl;
        size_t ElementSize;
        size_t count;
        link *Last;
        link *First;
        unsigned Flags;
};
```

We store the root of the list in the "First" pointer, and to save us in many occasions a long trip through the list we store a pointer to the last item of the list. As usual there is a count field telling how many items we have, an ElementSize field telling us how big each item is.

Note that First and Last are pointers to a "link" structure. Here it is:

```
typedef struct _link {
        struct _link *Next;
        char Data[];
} link;
```

Instead of storing a pointer to the data, we store the data right behind the pointer. This is possible only when we know how big each item will be. When we allocate a link structure we allocate the size of the element + size of a pointer. With this organization we have the minimal overhead for lists that is theoretically possible: just one pointer. The overhead for storing items in a list is proportional to the number of elements in the list. For very long lists, storing 1 million items needs an overhead of 4 million bytes using this schema, 8 million bytes using a single link to the data, and 12 million for a double linked list.

2.6.1 Creating a list

There isn't a lot of work to create the starting structure. Since there is no sense in getting an initial size, our constructor has only one obligatory element: the size of the elements to be stored in the list.

```
List *newList(int elementsize)
{
        List *result;

        if (elementsize <= 0)
                return NULL;
        result = GC_malloc(sizeof(List));
        if (result) {
                result->ElementSize = elementsize;
                result->lpVtbl = &listlpVtbl;
        }
        return result;
}
```

We assign only two fields and rely on GC_malloc returning memory initialized to zero. We set the element size and the table of functions that this object will support. If there is no more memory left, or the element size is nonsense, we return NULL.

7. Isn't it a good "catch all" explanation? Actually it can mean: "I remain consistent with my bugs"

2.6.2 Adding elements

We use the same interface as the Add function in the ArrayList container.

```
static int Add(List *l,void *elem)
{
        if (l == NULL || elem == NULL)
                return LIST_ERROR_BADARG;
        if (l->Flags &LIST_READONLY)
                return LIST_ERROR_READONLY;
        link *newl = new_link(l,elem);
        if (newl == NULL)
                return LIST_ERROR_NOMEMORY;
        if (l->count ==  0) {
                l->First = l->Last = newl;
        }
        else {
                l->Last->Next = newl;
                l->Last = newl;
        }
        return ++l->count;
}
```

We do not accept NULL elements in the list since it is a container that should hold elements of equal size, and a list of only NULLs doesn't make a lot of sense anyway.

We allocate a new link element to hold the data and a pointer. If the list is empty, this will be the first element and also the last one. We set the pointer accodingly. If the list is not empty, we add the new element at the end of the list by setting the "next" pointer of the last element to the new one, and then setting the last element to this one. We increase the count and we are done.

2.6.3 Retrieving elements

```
static void * IndexAt(List &l,int position)
{
        link *rvp;

        if (position >= (signed)l.count || position < 0) {
                ContainerRaiseError(CONTAINER_ERROR_INDEX);
                return NULL;
        }
        rvp = l.First;
        while (position) {
                rvp = rvp->Next;
                position--;
        }
        return rvp->Data;
}
```

Here we should return a pointer to the data so we can't return an integer error code.[8] In case the index is wrong, we throw an exception. If the user has subclassed the exception procedure or the exception procedure somehow returns, we return NULL.

We set our roving pointer rvp to the first element, then we go through the elements until the given position is reached.

If the list has zero elements, this error will be catched in the line before with the condition:

8. We could have done that if we had sticked to a convention of never returning directly a result but a result code of the operation, as Microsoft proposed in the implementation of their strsafe library. The problem with that approach is that the interface is too cumbersome.

```
        position >= count
```

If the count is zero, position will be greater or equal than zero, since we catch the cases where the position is negative. The roving pointer rvp must be a valid pointer, and we should be able to go through the list until the desired position. Any error here will provoke a trap, and a trap here can mean only that we have an invalid list.

In lcc-win32 we can overloade the operator `[ ]` (indexing operator) with the same signature as IndexAt, to allow the user to write in the more natural notation

```
             L[2]
```

instead of

```
             L->lpVtbl->IndexAt(L,2);
```

The advantage is just a matter of easy of use.

The declaration of the overloaded indexing operator would be:

```
        void *operator [ ](List *l, int position);
```

Chapter 2

Network Programming

4.1 Introduction

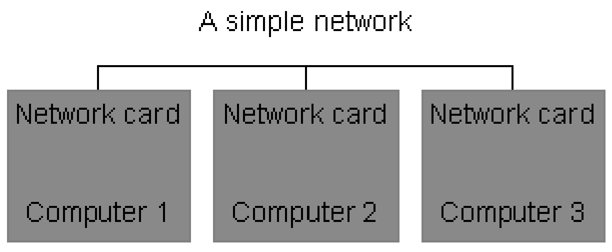
Network programming under windows started with the windows socket implementation under windows 3.0. That implementation was a port of the sockets implementation of Unix to windows, that added some support for the asynchronous calls under the weak multitasking of the 16 bit windows implementation.

When windows passed to 32 bits under windows 95, the sockets implementation improved, of course, since a real multitasking operating system was running.

Based on the windows sockets implementation, Microsoft released first the wininet interface, later the winhttp interface. The wininet interface is better for people that are concerned with some other protocols as http of course, and it is a more low level interface than winhttp. Of course "low level" is here very relative. Having implemented a full FTP protocol under windows 3.1, the wininet interface is kilometer higher than the bare windows sockets interface.

4.1.1 What is a network?

Let's start with a short review of the basic network terminology. The figure below demonstrates a simple network that you might find in a small business or in the home. Each machine has a network adapter that connects it to the network, as well as a name that uniquely identifies it. The network adapter determines the type of network, generally either Ethernet, WI-FI, or older types of networks like Token Ring . The adapter also controls the media used for the network: coax, twisted pair, radio waves, etc. The important thing to recognize is that all of the machines in a simple network like this can communicate with all of the others equally.



The machines send electrical signals through the medium used by the network, be it coax, twisted pair, or radio waves. This signals are encoded in precise bit patterns called protocols, that give meaning to the bit stream. To comunicate with one another, machines follow specific rules for speech, unlike people. The slightest interference, the slightest error in the sequence and the machines lose completely the conversation and get stuck. Protocols are the base of all the network.

Many protocols have been used in the PC, from the early LANMAN days, to now, where TCP/IP has displaced all others.

With the rise of the internet , the internet protocol has been accepted as a quasi universal standard. This protocol runs over other more basic protocols like the ethernet protocol, in the case of coax, or token ring, or whataver is actually sending and receiving the data.

But let’s get practical. Let’s start a small program that we can do without a lot of effort.

We will start then, with a simple program to read files from the internet. We will use the library of Microsoft provided with the operating system: `Winhttp.lib`. The header file is `winhttp.h`, that you should include in all the programs that use this examples. You should obviously include in the linker command line the library itself, winhttp.lib. This library is just an import library for `winhttp.dll` that you should normally have in your windows directory. Other header files are necessary too, like `stdlib.h` for getting the prototype of the “`malloc`” function, etc.

4.2 Protocols

Protocols are standardized exchanges between two automata: a “client”, that asks some information or resource from the “server” automaton, that manages that information and sends it through the network. A protocol has a standard interchange format: the precise sequence of interactions between the two machines is fixed in all details to make automated communication between them possible.

The information exchanged can be anything: an image, sound, an e-mail, hyper-text you name it. It can be even a pdf file where you read this lines.

4.3 The HTTP Protocol

The **H**yper **T**ext **T**ransfer **P**rotocol relies on “transactions”, i.e. a standardized exchange between two computers. Within a HTTP transaction, you exchange information with another computer elsewhere on a network. The information exchanged can be a file that contains data in the form of text, sound, video, or whatever, or it can be the results of a database query. A piece of information exchanged over a network is called a resource. Normally the computer that sends a resource is the server and the computer that receives that resource is a client.

The process of obtaining a resource using the HTTP protocol requires that a series of messages be exchanged between the client and the server. The client begins the transaction by sending a message that requests a resource. This message is called an HTTP request, or sometimes just a request. An HTTP request consists of the following components.

1) Method, Uniform Resource Identifier (URI), protocol version number

2) Headers

3) Entity body

The request is sent as plain text over the network. It uses the TCP/IP port 80.

When a server receives a request, it responds by sending a message back to the client. The message sent by the server is called an HTTP response. It consists of the following components.

1) Protocol version number, status code, status text

2) Headers

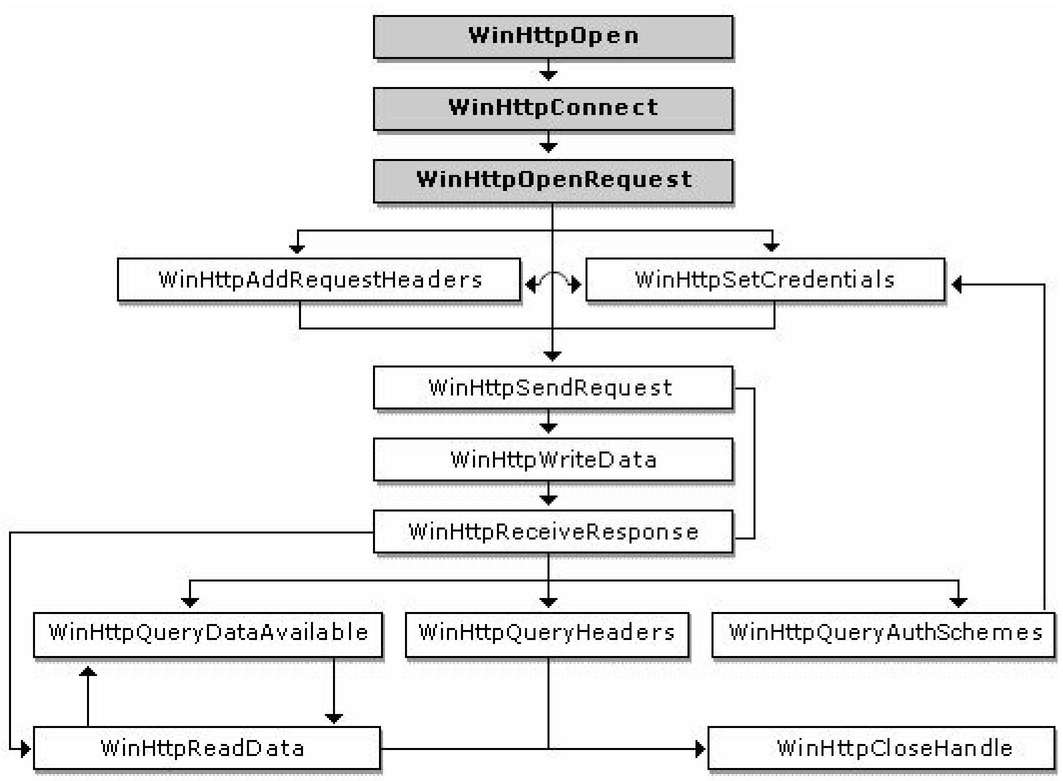
3) Entity body

The response either indicates that the request cannot be processed, or provides requested information. Depending on the type of request, this can be information about a resource, such as its size and type, or can be some or all of the resource itself. The part of a response that includes some or all of the requested resource is called the "response data" or the "entity body,' and the response is not complete until all the response data is received.

4.3.1 GetHttpUrl

The interface for our function should be as simple as possible. It will receive two character strings, representing the name of the URL to retrieve, and the name of the output file where the file should be stored. If you are interested in using the resulting code you can skip this section.

We start by opening an http session. The general schema for an http session is like this:



Clasic. We open a session, connect, and send requests. In this case we are concerned only with retrieving the data, i.e. a “GET” request.

We do then an open, we connect, and start a request for a resource. We read from the headers some info (before we read the data, it would be nice to check that the resource actually exists) and accordingly we read the content of the file or not.

4.3.2 Implementation

We open a session using the WinHttpOpen API.

```
hSession = WinHttpOpen( L"lcc WinHTTP/1.0",
     WINHTTP_ACCESS_TYPE_DEFAULT_PROXY,
     WINHTTP_NO_PROXY_NAME,
     WINHTTP_NO_PROXY_BYPASS,
     0);

// Check to see if the session handle was successfully created.
if (hSession == NULL) {
     fRet = GetLastError();
     if (fRet == 0)
          fRet = -1;
     return fRet;
}
```

The first argument to WinHttpOpen is the name of the application that issues the request for data, or “user agent”. The user agent is the client application that requests a document from an HTTP server so that the server can determine the capabilities of the client software. In this case we send just a default name.

WinHttp uses a proxy if needed. We rely that a configuration utility has already set up the proxy settings for us, and request that WinHttp uses the default configuration.

If we can’t open the session, we just return the error code.

If all goes well, we initialize our local variables. We zero the rcContext structure, where we store the relevant information for our session, and we translate the name of the URL into UNICODE. The winhttp primitives are all in UNICODE, and there is no ANSI equivalent.

```
// Initialize local stuff
ZeroMemory(&urlComp, sizeof(urlComp));
urlComp.dwStructSize = sizeof(urlComp);
memset(&rcContext,0,sizeof(rcContext));
mbstowcs(szWURL,url,1+strlen(url));

// Use allocated buffer to store the Host Name.
urlComp.lpszHostName        = szHost;
urlComp.dwHostNameLength    = sizeof(szHost) / sizeof(szHost[0]);

// Set non zero lengths to obtain pointer to the URL Path.
/* note: if we threat this pointer as a NULL terminated string
this pointer will contain Extra Info as well. */
urlComp.dwUrlPathLength = -1;

// Crack HTTP scheme.
urlComp.dwSchemeLength = -1;
```

Parsing an URL is a tricky business that we better leave for an API than trying to do this ourselves.

```
if (!WinHttpCrackUrl(szWURL, 0, 0, &urlComp)) {
     goto cleanup;
}
```

Note that all errors are processed using a “goto cleanup”, what simplifies the error handling. The famous “goto” statement is not that bad after all.

This is it. We attempt to open a connection now.

```
// Open an HTTP session.
```

```
rcContext.hConnect = WinHttpConnect(hSession, szHost,
     urlComp.nPort, 0);
if (NULL == rcContext.hConnect)
{
     goto cleanup;
}
```

Note that no actual connection will be done until we start a request. This is a “GET” request.

```
dwOpenRequestFlag = (INTERNET_SCHEME_HTTPS == urlComp.nScheme) ?
     WINHTTP_FLAG_SECURE : 0;

// Open a "GET" request.
rcContext.hRequest = WinHttpOpenRequest(rcContext.hConnect,
     L"GET", urlComp.lpszUrlPath,
     NULL, WINHTTP_NO_REFERER,
     WINHTTP_DEFAULT_ACCEPT_TYPES,
     dwOpenRequestFlag);
if (rcContext.hRequest == 0)
     goto cleanup;
```

Now we are ready to send our request. This will open a connection.

```
// Send the request.
if (!WinHttpSendRequest(rcContext.hRequest,
     WINHTTP_NO_ADDITIONAL_HEADERS, 0,
     WINHTTP_NO_REQUEST_DATA, 0, 0,0))
     goto cleanup;
```

We wait for the answer.

```
if (!WinHttpReceiveResponse(rcContext.hRequest,0))
     goto cleanup;
```

We are now ready to query the headers of the resource we are tryingt to obtain. The reason is simple: if our routine received a request for an inexistent resource, many servers will send data anyway containing some HTML that will show the famous page “Unable to find server” or similar.We surely do not want to get that, so we have to scan the headers to see if we get a “404”, the http error for indicating that the resource is unavailable.

We do not know how long the headers can be. We first query the length of the buffers, allocate memory, then we make the request to get the actual header data.

```
dwSize = 0;
WinHttpQueryHeaders(rcContext.hRequest,
          WINHTTP_QUERY_RAW_HEADERS_CRLF ,
          WINHTTP_HEADER_NAME_BY_INDEX,NULL,
          &dwSize,WINHTTP_NO_HEADER_INDEX);
if (GetLastError() != ERROR_INSUFFICIENT_BUFFER ) {
     goto cleanup;
}
dwSize++; // count the trailing zero
swzHeaders = malloc(dwSize * sizeof(wchar_t));
szHeaders = malloc(dwSize);
if (swzHeaders == NULL || szHeaders == NULL) {
     goto cleanup;
}
dwSize--;
WinHttpQueryHeaders(rcContext.hRequest,
          WINHTTP_QUERY_RAW_HEADERS_CRLF ,
          WINHTTP_HEADER_NAME_BY_INDEX,
          swzHeaders,&dwSize,WINHTTP_NO_HEADER_INDEX);
```

We got the headers. Now we parse them to find the return code in them. The standard HTTP specifies a response like:

```
HTTP/1.1 200 OK
Date: Fri, 07 May 2004 09:08:14 GMT
Server: Microsoft-IIS/6.0
P3P: CP="ALL IND DSP COR ADM CONo CUR CUSo IVAo IVDo PSA PSD TAI TELo
OUR SAMo CNT COM INT NAV ONL PHY PRE PUR UNI"
X-Powered-By: ASP.NET
Content-Length: 39601
Content-Type: text/html
Expires: Fri, 07 May 2004 09:08:14 GMT
Cache-control: private
```

We are interested in the first line, that contains the return code for the operation. We just skip the HTTP/1.1 and get it:

```
memset(szHeaders,0,dwSize);
wcstombs(szHeaders,swzHeaders,dwSize);
char *p = szHeaders;
while (*p != ' ')
     p++;
while (*p == ' ')
     p++;
sscanf(p,"%d",&rc);
if (rc == 404) {
     rcContext.Status = 404;
     goto cleanup;
}
```

The next thing to do is to open the output file. If we can't open it, there is no point in going further. We close the session and return an error code.

```
rcContext.OutputFile = fopen(outfile,"wb");
if (rcContext.OutputFile == NULL) {
     WinHttpCloseHandle(hSession);
     return -2;
}
```

Now we have everything. We have an open file ready to receive the data, a correct answer from the server that tells that the file exists, so we have just to loop getting the data chunks until there is none left.

```
do  {
     // Check for available data.
     dwSize = 0;
     if(!WinHttpQueryDataAvailable( rcContext.hRequest, &dwSize ))
          goto cleanup;
     // Allocate space for the buffer.
     char *pszOutBuffer = malloc(dwSize+1);
     if( !pszOutBuffer ) {
          goto cleanup;
     }
     // Read the data.
     ZeroMemory( pszOutBuffer, dwSize+1 );
     if( !WinHttpReadData( rcContext.hRequest,
               (LPVOID)pszOutBuffer,
               dwSize, &dwDownloaded ) ) {
               free(pszOutBuffer);
               goto cleanup;
     }
     // OK Write the data
```

```
            fwrite(pszOutBuffer,1,dwDownloaded,
                                rcContext.OutputFile);
            // Free the memory allocated to the buffer.
            free(pszOutBuffer);
        } while( dwSize > 0 );
```

We are finished. We fall through to the cleanup section.

4.4 The FTP protocol

The library winhttp.lib, that we used for implementing the HTTP "GET" functionality above is OK for its intended use: HTTP. There are however several other interesting protocols available to get information from the net, like FTP, Gopher, and others. We will turn ourselves to another high level library: wininet.lib. This library (with its header file wininet.h) implements FTP, Gopher, and HTTP. It comes with an embedded caching schema, and many other advanced features. We will just use a tiny part of it, the one that implements the FTP protocol suite.

FTP means File Transfer Protocol, and is one of the oldest protocols around. It is a 8 bit client/server protocol able to handle any type of file any need to encode its contents, unlike MIME or UUENCODE. The problem with ftp is that it is very slow to start (high latency), and needs, when using manually, a lengthy login procedure.

The current standard for FTP is RFC 959, which obsoleted the previous specification RFC 765. The first FTP specification was RFC 114, written by A. Bhushan in the MIT project MAC the 16 April 1971.

Yes. It is a really old protocol.

4.4.1 Implementing the ftp "GET"

We use a simple interface again, ignoring all complexities. GetFtpUrl needs 3 arguments:

1) The name of the host

2) The name of the file to get

3) The name of the local file where the remote file will be written

```
int GetFtpUrl(char *host,char *infile,char *outfile)
{
    HINTERNET hOpen,hConnect;
    int fret = -1;
/* The first thing to do is to check that there is an internet connection. If the local machine is not connected to the internet a call to this function will bring up a dialog box and a series of wizards to set up the connection..
*/
    fret = InternetAttemptConnect(0);
    if (fret)
        return fret;
/* We can assume now that an internet connection exists. We initialize the inet library specifying the default proxy settings, and using some character string as the name of the "user agent" */
    hOpen = InternetOpen ( "FTP lcc ",
      INTERNET_OPEN_TYPE_PRECONFIG , NULL, 0, 0) ;
    if (!hOpen )
        return -1;
/* We establish now the connection, using the default FTP port, and passive mode. We pass NULL as user name and password. This means that we always use the "anonymous" login */
```

```
    hConnect = InternetConnect ( hOpen,
         host,INTERNET_INVALID_PORT_NUMBER,
         NULL,  NULL, INTERNET_SERVICE_FTP,
         INTERNET_FLAG_PASSIVE , 0);
    if ( hConnect)  {
```

/* OK. We arrive at the interesting part. We retrieve the file using INTERNET_FLAG_RELOAD, what means a download is forced of the requested file, object, or directory listing from the origin server, not from the cache . Besides this, we always use binary mode for all transfers[8] */

```
         fret = FtpGetFile (hConnect,infile, outfile,
              FALSE, // Do not fail if local file exists
              INTERNET_FLAG_RELOAD,
              FTP_TRANSFER_TYPE_BINARY, 0 );
         if (fret == 0)
              fret = GetLastError();
         else
              fret = 0;
         // Cleanup
         InternetCloseHandle (hConnect);
    }
    else
         fret = GetLastError();
    InternetCloseHandle(hOpen);
    return fret;
}

int main(void)
{
    return GetFtpUrl("ftp.cs.virginia.edu",
              "/pub/lcc-win32/README",
              "README");
}
```

To give you an idea, when the first FTP protocol implementations under windows 3.0 were monster programs of several thousand lines. Of course those thousands of lines are still there, in the code of those FtpGetFile primitives. The advantage is that you do not have to worry about it.

To link this program you should use the wininet.lib import library.

4.5 Querying the network parameters

The program ipconfig shows the parameters of the TCPIP configuration. We will make here a similar program, to give you an idea how you can get those parameters under program control.

We will use the APIs defined in the IP helper API. The header file is iphlp.h and the library to include is iphlp.lib.

The interface for our program is very simple. There is no parameters, and the return value is zero if everything went OK, an error code otherwise.

```
#include <stdio.h>
#include <stdlib.h>
#include <string.h>
#include <windows.h>
#include <winsock2.h>
#include <iphlpapi.h>
```

8. The FTP protocol has two modes of transmission: **binary**, where no modifications are done to the transmitted data, and **text**, where the sequence \r\n will be translated as a single \n. The text mode will destroy an executable file or zip file that can contain embedded \r\n sequences.

```
int main(void)
{
     FIXED_INFO*pFixedInfo;
     IP_ADDR_STRING*pIPAddr;
     ULONG     ulOutBufLen;
     DWORD     dwRetVal;
     int rc;
/* We use the GetNetworkParams API to query the host name, the domain name, and other
related information. We make two calls: in the first one we give an insufficient buffer,. This call
fails obviously, returning in the ulOutBufLen the necessary buffer length. Using this information
we allocate the necessary memory, and then call GetNetworkParams again. This is a common
interface with many network APIs that need buffers of varying length.
*/
     pFixedInfo = malloc( sizeof( FIXED_INFO ) );
     ulOutBufLen = sizeof( FIXED_INFO );

     rc = GetNetworkParams( pFixedInfo, &ulOutBufLen );
     if (rc == ERROR_BUFFER_OVERFLOW ) {
          free( pFixedInfo );
          pFixedInfo = malloc ( ulOutBufLen );
     }
     else return GetLastError(); // failed for another reason. Exit.
     // Now this call is for real
     dwRetVal = GetNetworkParams( pFixedInfo, &ulOutBufLen );
     if ( dwRetVal != NO_ERROR ) {
          printf("Call to GetNetworkParams failed.\nError code %d\n",
               GetLastError());
          return 1;
     }
     // Show the retrieved information
     printf("\tHost Name: %s\n", pFixedInfo -> HostName);
     printf("\tDomain Name: %s\n", pFixedInfo -> DomainName);
     printf("\tDNS Servers:\n");
     printf("\t\t%s\n", pFixedInfo -> DnsServerList.IpAddress.String);
     // The server list is stored as a linked list. Go through that list until we hit a NULL.
     pIPAddr = pFixedInfo -> DnsServerList.Next;
     while ( pIPAddr ) {
          printf("\t\t%s\n", pIPAddr -> IpAddress.String);
          pIPAddr = pIPAddr -> Next;
     }
     // Show the other parameters
     printf("\tEnable Routing: %s\n",
          (pFixedInfo -> EnableRouting) ? "Yes" : "No");

     printf("\tEnable Proxy: %s\n",
          (pFixedInfo -> EnableProxy) ? "Yes" : "No");

     printf("\tEnable DNS: %s\n",
          (pFixedInfo -> EnableDns) ? "Yes" : "No" );

     IP_ADAPTER_INFO*pAdapterInfo,*pAdapter;
/* The same technique as above. We pass to the API a buffer of a given length, and if it doesn't
suffice we allocate the buffer in the returned length
*/
     pAdapterInfo = malloc(sizeof(IP_ADAPTER_INFO));
     ulOutBufLen = sizeof(IP_ADAPTER_INFO);
     rc = GetAdaptersInfo( pAdapterInfo, &ulOutBufLen);
     if (rc != ERROR_SUCCESS) {
          free(pAdapterInfo);
```

```
        pAdapterInfo = malloc (ulOutBufLen );
    }
    dwRetVal = GetAdaptersInfo( pAdapterInfo, &ulOutBufLen);
    if (dwRetVal != NO_ERROR) {
        printf("Call to GetAdaptersInfo failed.\nError %d\n",
            GetLastError());
        return 1;
    }
    pAdapter = pAdapterInfo;
/* We have now a linked list of adapters. Go through that list printing the information. */
    while (pAdapter) {
        printf("\tAdapter Name: \t%s\n", pAdapter->AdapterName);
        printf("\tAdapter Desc: \t%s\n", pAdapter->Description);
        printf("\tAdapter Addr: \t%#x\n", pAdapter->Address);
        printf("\tIP Address: \t%s\n",
            pAdapter->IpAddressList.IpAddress.String);
        printf("\tIP Mask: \t%s\n",
            pAdapter->IpAddressList.IpMask.String);
        printf("\tGateway: \t%s\n",
            pAdapter->GatewayList.IpAddress.String);
        if (pAdapter->DhcpEnabled) {
            printf("\tDHCP Enabled: Yes\n");
            printf("\t\tDHCP Server: \t%s\n",
                pAdapter->DhcpServer.IpAddress.String);
            printf("\tLease Obtained: %ld\n",
                pAdapter->LeaseObtained);
        }
        else printf("\tDHCP Enabled: No\n");
        if (pAdapter->HaveWins) {
            printf("\t\tPrimary Wins Server: \t%s\n",
                pAdapter->PrimaryWinsServer.IpAddress.String);
            printf("\t\tSecondary Wins Server: \t%s\n",
                pAdapter->SecondaryWinsServer.IpAddress.String);
        }
        else printf("\tHave Wins: No\n");
        pAdapter = pAdapter->Next;
    }
/* We query now the interface information */
    IP_INTERFACE_INFO* pInfo;
    pInfo = (IP_INTERFACE_INFO *) malloc( sizeof(IP_INTERFACE_INFO) );
    rc = GetInterfaceInfo(pInfo,&ulOutBufLen);
    if (rc == ERROR_INSUFFICIENT_BUFFER) {
        free(pInfo);
        pInfo = (IP_INTERFACE_INFO *) malloc (ulOutBufLen);
        printf("ulLen = %ld\n", ulOutBufLen);
    }
    else {
        printf("GetInterfaceInfo failed with error %d\n",
            GetLastError());
        return 1;
    dwRetVal = GetInterfaceInfo(pInfo, &ulOutBufLen);
    if (dwRetVal == NO_ERROR ) {
        printf("Adapter Name: %S\n", pInfo->Adapter[0].Name);
        printf("Adapter Index: %ld\n", pInfo->Adapter[0].Index);
        printf("Num Adapters: %ld\n", pInfo->NumAdapters);
    }
/* Instead of printing a more or less meaningless error message, we can use FormatMessage
to give a more comprehensible description of the problem */
    if (dwRetVal) {
        LPVOID lpMsgBuf;
```

```
          if (FormatMessage(
               FORMAT_MESSAGE_ALLOCATE_BUFFER |
                    FORMAT_MESSAGE_FROM_SYSTEM |
                    FORMAT_MESSAGE_IGNORE_INSERTS,
               NULL,
               dwRetVal,
               MAKELANGID(LANG_NEUTRAL, SUBLANG_DEFAULT),
               (LPTSTR) &lpMsgBuf,
               0,
               NULL ))
          {
               printf("\tError: %s", lpMsgBuf);
          }
          LocalFree( lpMsgBuf );
     }
/* Show the information for the ip address table */
     MIB_IPADDRTABLE*pIPAddrTable;
     DWORD              dwSize;
     struct in_addr IPAddr;
     char *strIPAddr;

     pIPAddrTable = malloc(sizeof(MIB_IPADDRTABLE));
     dwSize = 0;
     IPAddr.S_un.S_addr = ntohl(pIPAddrTable->table[1].dwAddr);
     strIPAddr = inet_ntoa(IPAddr);
     rc = GetIpAddrTable(pIPAddrTable, &dwSize, 0);
     if (rc == ERROR_INSUFFICIENT_BUFFER) {
          free( pIPAddrTable );
          pIPAddrTable = malloc ( dwSize );
     }
     dwRetVal = GetIpAddrTable( pIPAddrTable, &dwSize, 0 );
     if (dwRetVal != NO_ERROR ) {
          printf("Call to GetIpAddrTable failed.\nError %d\n",
                    GetLastError());
          return 1;
     }
/* Now show the information */
     printf("Address: %#x\n", pIPAddrTable->table[0].dwAddr);
     unsigned int mask = pIPAddrTable->table[0].dwMask;
     printf("Mask:    %d.%d.%d.%d\n",0xff&mask,0xff&(mask >> 8),
          0xff&(mask >> 16),0xff&(mask >> 24));
     printf("Index:   %ld\n", pIPAddrTable->table[0].dwIndex);
     printf("BCast:   %ld\n", pIPAddrTable->table[0].dwBCastAddr);
     printf("Reasm:   %ld\n", pIPAddrTable->table[0].dwReasmSize);
     /* Get the statistics about IP usage */
     MIB_IPSTATS   *pStats;

     pStats = (MIB_IPSTATS*) malloc(sizeof(MIB_IPSTATS));

     if ((dwRetVal = GetIpStatistics(pStats)) != NO_ERROR) {
          printf("\tError  %d getting stats.\n",GetLastError());
          return 1;
     }
     printf("\tNumber of IP addresses: %ld\n", pStats->dwNumAddr);
     printf("\tNumber of Interfaces: %ld\n", pStats->dwNumIf);
     printf("\tReceives: %ld\n", pStats->dwInReceives);
     printf("\tOut Requests: %ld\n", pStats->dwOutRequests);
     printf("\tRoutes: %ld\n", pStats->dwNumRoutes);
     printf("\tTimeout Time: %ld\n", pStats->dwReasmTimeout);
     printf("\tIn Delivers: %ld\n", pStats->dwInDelivers);
```

```
        printf("\tIn Discards: %ld\n", pStats->dwInDiscards);
        printf("\tTotal In: %ld\n",
             pStats->dwInDelivers+pStats->dwInDiscards);
        printf("\tIn Header Errors: %ld\n", pStats->dwInHdrErrors);
        /* Get the TCP statistics */
        MIB_TCPSTATS*pTCPStats;

        pTCPStats = (MIB_TCPSTATS*) malloc (sizeof(MIB_TCPSTATS));

        if ((dwRetVal = GetTcpStatistics(pTCPStats)) != NO_ERROR)
             printf("Error %d getting TCP Stats.\n",GetLastError());
        printf("\tActive Opens: %ld\n", pTCPStats->dwActiveOpens);
        printf("\tPassive Opens: %ld\n", pTCPStats->dwPassiveOpens);
        printf("\tSegments Recv: %ld\n", pTCPStats->dwInSegs);
        printf("\tSegments Xmit: %ld\n", pTCPStats->dwOutSegs);
        printf("\tTotal # Conxs: %ld\n", pTCPStats->dwNumConns);
   }
```

Getting accurate information about the TCP and IP statistics is very important when you want to measure the performance of a network program. By getting the count of the packets transmitted, connections, etc, you can measure exactly how is the performance of your network application.

4.6 Writing “ping”

“Ping” is a small program that attempts to send an echo request to another machine. If the response arrives, the other machine is up and running, if not... well, there is a problem with the physical connection somewhere or the other machine is down.

Simple.

Lcc-win32 provides a “ping” function, that can be used to “ping” a host under program control. To use that, it is just necessary to include the “ping.h” header file. The simplest program using ping can be written like this:

```
   #include <ping.h>
   #include <stdio.h>
   int main(int argc,char *argv[])
   {
        PingInterface p;
        memset(&p,0,sizeof(p));
        p.HostName = argv[1]);
        if (ping(&p)) {
             printf("Host %s is up\n",argv[1]);
        }
        else
             printf("Host %s is down\n",argv[1]);
   }
```

4.6.1 How does it work?

The algorithm followed by the implementation of ping is to open a connection (a socket) using the “raw” state, i.e. without using any higher level protocol, not even the TCP protocol. Using this socket we write an ICMP packet (Internet Control Management Protocol) into the buffer we are going to send, and we wait for the answer. When the answer arrives we record how much time it took for the packet to make the round trip.

It sounds simple but it isn't. It took me quite a while to make an implementation that is at the same time easy to use and robust. For instance, what happens if the other side never answers? It would be really bad if ping would freeze waiting for an answer that will never come.

Many other problems can occur, and within the "PingInterface" structure there are a lot of fields that inform you what is going on.

The basic design principle is that you establish a callback function that is called by the ping function each time a packet arrives or a timeout is detected.

A more sophisticated usage of ping() is the "remake" of the program of the same name. Here is a possible implementation of that.

First we write a callback function to show progress in the screen as we receive a packet.

```
#include <ping.h>
int PrintReport(PingInterface *Data)
{
     if (Data->Errorcode == WSAETIMEDOUT) {
          printf("Timed out\n");
          return 1;
     }
     printf("%d bytes from %s:",Data->Bytes, Data->ip);
     printf(" icmp_seq = %d. ",Data->Seq);
     printf(" time: %d ms ",Data->Time);
     printf("\n");
     return 1;
}
```

This function is called by ping() and just prints out the fields. Note that we test the error code flag to see if we are being called because of a timeout or because of a packet arrived.

In this function we could send a message to a GUI window, or we would update some pregress control, etc.

The main function is now trivial. We zero the interface structure, we set some fields and there we go.

```
int main(int argc, char **argv)
{
     PingInterface p;
     int r;

     memset(&p,0,sizeof(p));
     // We set the host name field
     p.HostName = argv[1];
     // We modify the default time between packets
     p.SleepTime = 500;
     // If we time out more than 5 times we exit
     p.MaxTimeouts = 5;
     // We set our callback
     p.Callback = PrintReport;
     r = ping(&p);
     if (r == 0) {
          printf("%s is down\n",p.HostName);
          return 1;
     }
     printf("\n");
     printf("\n%d packets from %s (%s). ",
          p.TotalPackets, p.HostName,p.ip);
     printf("Received: %d, Sent: %d\n",p.TotalReceived,p.TotalSent);
     if (p.TotalPackets == 0)
          p.TotalPackets = 1;
```

```
        printf("Max time: %d ms, Min time %d ms, Avg time= %g ms\n",
             p.MaxTime,p.MinTime,
             (double)p.TotalTime/ (double) p.TotalPackets);
        return 0;
    }
```

4.7 Client/Server programming using sockets

There are two distinct types of socket network applications: Server and Client. The server is normally the propietary of a ressource: a data file, an image, or other information that it serves to its clients. Clients request information from the server, and display it to the user.

Servers and Clients have different behaviors; therefore, the process of creating them is different.

Client	*Server*
Initialize WSA.	Initialize WSA
Create a socket	Create a socket
Connect to the server	Listen on the socket
	Accept a connection
Send and receive data	Send and receive data
Disconnect	Disconnect

4.7.1 Common steps for server and client

4.7.1.1 Initializing

All Winsock applications must be initialized to ensure that Windows sockets are supported on the system. To initialize Winsock you should call the WSAStartup function, giving it the version number you want to use, and the address of a WSADATA structure, where windows writes information about the type of network software that is running.

A typicall call would be:

```
WSADATA wsadata;
if (WSAStartup(MAKEWORD(2,1),&wsaData) != 0){
     return GetLastError();
}
```

The cryptic MAKEWORD(2,1) means we want at least version 2.1 of the network software. Note that the library included with lcc-win32 doesn’t need this step, since it will perform it automatically if it detects that the network wasn’t initialized.

4.7.1.2 Creating a socket

Once initilized, we can create a socket, trough which we are going to send and receive the data. We call for this the ‘socket’ function:

```
SOCKET Socket = socket( AF_INET, SOCK_STREAM, IPPROTO_TCP );
```

The error report of the socket call is a return value of `INVALID_SOCKET`. A typical sequence would be:

```
if ( Socket == INVALID_SOCKET ) {
        printf( "Error: %ld\n", WSAGetLastError() );
    }
```

Note that under the UNIX operating system, socket descriptors are equivalent to file handles. This is not the case under windows. Furthermore, under UNIX all sockets descriptors are small positive numbers. This is not the case under windows. You will see under UNIX code that looks like this:

```
    s = socket(...);
    if (s == -1)    /* or s < 0 */
        {...}
```

This will not work under windows or produce a series of compiler warnings about signed/ unsigned comparisons. The preferred style is as shown above: comparing explictely with the `INVALID_SOCKET` constant.

4.7.2 Server side

4.7.2.1 Binding a socket

For a server to accept client connections, it must be *bound* to a network address within the system. This code demonstrates how to bind a socket to an IP address and port. Client applications use the IP address and port to connect to the host network.

First we create a sockkaddr object, that contains the type of network (we use AF_INET), the server IP number (we use the local loop address 127.0.0.1) and the port in that IP number we want to connect to. We can use any port number between 1024 and 65535.

```
    sockaddr_in service;
    service.sin_family = AF_INET;
    service.sin_addr.s_addr = inet_addr( "127.0.0.1" );
    service.sin_port = htons( 49025 );
```

Second, we bind the socket to this network address.

```
    int rc =  bind( m_socket, (SOCKADDR*) &service, sizeof(service) );
    if (rc == SOCKET_ERROR ) {
        printf( "bind() failed.\n" );
    }
```

4.7.2.2 Listening on a socket

After the socket is bound to an IP address and port on the system, the server must then listen on that IP address and port for incoming connection requests.

To listen on a socket call the listen function, passing the created socket and the maximum number of allowed connections to accept as parameters.

```
    if ( listen( Socket, 1 ) == SOCKET_ERROR )
        printf( "Error listening on socket.\n");
```

4.7.2.3 Accepting connections.

Once the socket is listening for a connection, we must handle connection requests on that socket. To accept a connection on a socket we create a temporary socket object for accepting connections.

```
    SOCKET AcceptSocket;
```

Create a continuous loop that checks for connections requests. If a connection request occurs, call the accept function to handle the request.

```
    printf( "Waiting for a client to connect...\n" );
```

```
while (1) {
    AcceptSocket = SOCKET_ERROR;
    while ( AcceptSocket == SOCKET_ERROR ) {
        AcceptSocket = accept( Socket, NULL, NULL );
    }
```

When the client connection has been accepted, assign the temporary socket to the original socket and stop checking for new connections.

```
        printf( "Client Connected.\n");
        Socket = AcceptSocket;
        break;
    }
```

There we go, we have a socket ready to send and receive data.

4.7.3 Client side

For a client to communicate on a network, it must connect to a server. To connect to a socket we create a sockaddr_in object and set its values.

```
sockaddr_in clientService;
clientService.sin_family = AF_INET;
clientService.sin_addr.s_addr = inet_addr( "127.0.0.1" );
clientService.sin_port = htons( 49025 );
```

Call the connect function, passing the created socket and the sockaddr_in structure as parameters.

```
int rc;
rc = connect(Socket,(SOCKADDR*)&clientService,sizeof(clientService));
if ( rc  == SOCKET_ERROR) {
    printf( "Failed to connect.\n" );
}
```

4.7.4 Sending and receiving data

We can receive data from the network using the recv function. A typical call looks like this:

```
int bytesReceived = recv(Socket,buffer,sizeof(buffer),0 );
```

If we want to receive text, we ensure the zero terminated string with:

```
buffer[sizeof(buffer)-1] = 0;
bytesReceived = recv(Socket,buffer,sizeof(buffer)-1,0);
```

To send data we use the send function.

```
bytesSent = send(Socket, buffer, strlen(buffer), 0 );
```

This sends a character string through the network without the trailing zero.

4.7.5 Simplifying sockets programming with lcc-win32

Lcc-win32 provides functions that relieve you from programming all the above. A client looks like this:

```
#include <stdio.h>
#include <stdlib.h>
#include "netutils.h"

int main(int argc,char *argv[])
{
     Session session;
     char buf[256];
```

```
          memset(&session,0,sizeof(session));
          session.port = 25876;
          session.Host = "127.0.0.1";
          if (ClientConnect(&session)) {
               printf("Unable to connect\n");
               goto end;
          }
          if (Send(&session,5,"data")) {
               printf("Unable to send\n");
               goto end;
          }
          if (Receive(&session,5,buf)) {
               printf("Unable to receive\n");
               goto end;
          }
          buf[session.BytesReceived] = 0;
          printf("Received %d bytes: %.5s\n",
                    session.BytesReceived, buf);
     end:
          CloseSession(&session);
     }
```

Simple isn't it?

A server looks like this:

```
     #include <stdio.h>
     #include "netutils.h"
     int main(int argc,char *argv[])
     {
          Session session;
          char buf[8192];

          memset(&session,0,sizeof(session));
          session.port  = 25876;
          session.Host = "127.0.0.1";
          if (ServerConnect(&session))
               return 0;
          printf("Connected...\n");
          memset(buf,0,sizeof(buf));
          if (Receive(&session,sizeof(buf)-1,buf))
               return 0;
          printf("received request\n");
          printf("data is: %s\n",buf);
          if (Send(&session,5,"data"))
               return 0;
          CloseSession(&session);
     }
```

Basically those procedures implement all the steps described above for client and server sides. They are the building blocks for implementing the FTP or HTTP protocols we saw above. To use this functions include "netutils.lib" in the linker command line and include "netutils.h" to get the prototypes and structure declarations.