

# Ammunition (Reusable packages) - C++ interface

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Oct 10, 2014

This document describes ammunition (reusable packages written in C/C++).

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## 1 Introduction

This document describes ammunition (reusable packages written in C/C++). The packages are oriented towards creation of compiler and cross-compiler. Currently there are the following packages (their names

and tasks):

**allocate**

allocating and freeing memory with fixing some allocation errors

**vobject**

work with variable length objects

**objstack**

work with stacks of objects

**hashtab**

work with hash tables

**position**

work with source code positions

**errors**

output of compiler messages

**commline**

work with command line

**bits**

work with bit strings

**arithm**

implementing host machine-independently arbitrary precision integer numbers arithmetic

**IEEE**

implementing host machine-independently IEEE floating point arithmetic

**ticker**

timer

**spset**

Expandable sparse set

**cspset**

Compact expandable sparse set

**earley**

Earley parser

## 2 Package for allocating memory with fixing some allocation errors

Developing modern compilers it is necessary to avoid arbitrary limits on the length or number of any data structure by allocating all data structures dynamically. Here the package 'allocate' which implements allocation and freeing memory with automatic fixing allocation errors is suggested.

The package automatically calls action on situation 'no memory'. The action never returns control back because after calling function which processes allocation error the function 'abort' is always called. Therefore the function which processes allocation error should not return control back.

The interface part of the package is file 'allocate.h'. The implementation part is file 'allocate.cpp'. The interface contains class 'allocate' without any public constructors/destructors. The class has the following functions:

### Static public function 'change\_error\_function'

```
'void change_error_function
    (void (*error_function) (void)) (void)'
```

is used for changing up action on the situation 'no memory'. The function also returns former function which was early action on the situation 'no memory'.

### Static public function 'default\_error\_function'

```
'void default_error_function (void)'
```

is default action of the package on the situation 'no memory'. This action consists of output message '\*\*\* no memory \*\*\*' to standard error stream and calling function 'exit' with code equals to 1.

### Static public function 'malloc'

```
'void *malloc (size_t size)'
```

is analogous to ANSI C library function 'malloc'. The parameter is size of needed memory. The function returns address of allocated memory.

### Static public function 'calloc'

```
'void *calloc (size_t nel, size_t size)'
```

is analogous to ANSI C library function 'calloc'. The parameters have the same sense as in standard function 'calloc'. The function returns address of allocated memory.

### Static public function 'free'

```
'void free (void *ptr)'
```

is analogous to ANSI C library function 'free' but can accept nil pointer value. In this case function does nothing.

**Static public function ‘realloc’**

```
‘void *realloc(void *old, size_t size)’
```

is analogous to ANSI C library function ‘realloc’. The first parameter is old address of reallocated memory. The second parameter is new size of reallocated memory. The function returns new address of reallocated memory.

### 3 Package for work with variable length objects

The package ‘vlobject’ implements work with variable length object (VLO) and uses package ‘allocate’. Any number of bytes may be added to and removed from the end of VLO. If it is needed the memory allocated for storing variable length object may be expanded possibly with changing the object place. But between any additions of the bytes (or tailoring) the object place is not changed. To decrease number of changes of the object place the memory being allocated for the object is longer than the current object length.

The package uses package ‘allocate’. The interface part of the package is file ‘vlobject.h’. Defining macro ‘NDEBUG’ (e.g. by option ‘-D’ in C++ compiler command line) before the inclusion of the interface file disables fixing some internal errors and errors of usage of the package. The implementation part is file ‘vlobject.cpp’. The interface contains the following objects:

**Type ‘vlo\_t’**

describes a descriptor variable length object. The type is simply synonym of ‘class vlo’. All work with stack of objects is executed through the descriptors. It should remember that work with the object through several descriptors is not safe.

**Macro ‘VLO\_DEFAULT\_LENGTH’**

has value which is default initial size of memory is allocated for VLO when the object is created (with not given initial size). Original value of the macros is equal to 512. This macro can be redefined in C++ compiler command line or with the aid of directive ‘#undef’ before including the interface file.

**Class ‘vlo’**

The class contains the following functions:

**Public constructor ‘vlo’**

```
‘vlo (size_t initial_length = VLO_DEFAULT_LENGTH)’
```

is used for creation of descriptor of VLO with initial zero length. If the parameter value is absent, the value is equal to zero then the VLO initial allocated memory length is equal to ‘VLO\_DEFAULT\_LENGTH’.

**Public destructor ‘~vlo’**

```
‘~vlo (void)’
```

is used for deleting the descriptor of VLO and freeing memory used by the VLO.

**Public function ‘nullify’**

```
‘void nullify (void)’
```

makes that length of VLO of given descriptor will be equal to zero (but memory for VLO is not freed and not reallocated).

**Public function ‘tailor’**

```
‘void tailor (void)’
```

makes that length of memory allocated for VLO of given descriptor becomes equal to VLO length.

**Public function ‘length’**

```
‘size_t length (void)’
```

returns current length of VLO of given descriptor.

**Public functions ‘begin’, ‘end’, ‘bound’**

```
‘void *begin(void)’, ‘void *end(void)’, ‘void *bound(void)’
```

return pointer (of type ‘void \*’) to correspondingly the first, the last byte of VLO of given descriptor, and pointer to the last byte plus one. Remember that the object may change own place after any addition.

**Public function ‘shorten’**

```
‘void shorten (size_t n)’
```

removes n bytes from the end of VLO of given descriptor. VLO is nullified if its length is less than n.

**Public function ‘expand’**

```
‘void expand (size_t length)’
```

increases length of VLO of given descriptor on number of bytes given as the parameter. The values of bytes added to the end of VLO will be not defined.

**Public function ‘add\_byte’**

```
‘void add_byte (int b)’
```

adds byte given as the parameter to the end of VLO of given descriptor.

**Public function ‘add\_memory’**

```
‘void add_memory (void *str, size_t length)’
```

adds memory starting with address given as the first macro parameter and with length given as the second parameter to the end of VLO of given descriptor.

**Public function ‘add\_string’**

```
‘void add_string (const char *str)’
```

adds C string (with end marker 0) given as the parameter to the end of VLO of given descriptor. Before the addition the macro deletes last character of the VLO. The last character is suggested to be C string end marker 0.

## 4 Package for work with stacks of objects

The package ‘objstack’ is based on package ‘allocate’ and implements efficient work with stacks of objects (OS). Work with the object on the stack top is analogous to one with a variable length object. One motivation for the package is the problem of growing char strings in symbol tables. Memory for OS is allocated by segments. A segment may contain more one objects. The most recently allocated segment contains object on the top of OS. If there is not sufficient free memory for the top object than new segment is created and the top object is transferred into the new segment, i.e. there is not any memory reallocation. Therefore the top object may change its address. But other objects never change address.

The package uses package ‘allocate’. The interface part of the package is file ‘objstack.h’. Defining macro ‘NDEBUG’ (e.g. by option ‘-D’ in C++ compiler command line) before inclusion of the interface file disables fixing some internal errors and errors of usage of the package. The implementation part is file ‘objstack.cpp’. The interface contains the following objects:

### Type ‘os\_t’

describes a descriptor of stack of objects. The type is simply synonym of ‘class os’. All work with stack of objects is executed through the descriptors. It should remember that work with the stack through several descriptors is not safe.

### Macro ‘OS\_DEFAULT\_SEGMENT\_LENGTH’

has value which is default size of memory segments which will be allocated for OS when the stack is created (with not given initial segment size). This is also minimal size of all segments. Original value of the macros is equal to 512. This macro can be redefined in C++ compiler command line or with the aid of directive ‘#undef’ before including the interface file.

### Class ‘os’

The class contains the following functions:

#### Public constructor ‘os’

```
os (size_t initial_segment_length
    = OS_DEFAULT_SEGMENT_LENGTH)'
```

creates OS which contains the single zero length object. Minimum size of memory segments which will be allocated for OS is given as the parameter. If the parameter is absent the allocated memory segments length is equal to ‘OS\_DEFAULT\_SEGMENT\_LENGTH’. But in any case the segment length is always not less than maximum alignment.

#### Public destructor ‘os’

```
~os (void)'
```

is used for deleting the descriptor of OS and freeing memory used by the OS.

#### Public function ‘empty’

```
void empty (void)'
```

is used for removing all objects on OS and freeing all memory allocated for OS except for the first segment.

**Public function ‘top\_finish’**

```
‘void top_finish (void)’
```

creates new variable length object with initial zero length on the top of OS of given descriptor. The work (analogous to one with variable length object) with object which was on the top of OS is finished, i.e. the object will never more change address.

**Public function ‘top\_nullify’**

```
‘void top_nullify (void)’
```

makes that length of variable length object on the top of OS of given descriptor will be equal to zero.

**Public function ‘top\_length’**

```
‘size_t top_length (os)’
```

returns current length of variable length object on the top of OS of given descriptor.

**Public functions ‘top\_begin’, ‘top\_end’, ‘top\_bound’**

```
‘void *top_begin (void)’, ‘void *top_end (void)’,  
‘void *top_bound (void)’
```

return pointer to correspondingly the first, the last byte of variable length object on the top of OS of given descriptor, and pointer to the last byte plus one. Remember that the top object may change own place after any addition.

**Public function ‘top\_shorten’**

```
‘void top_shorten (size_t n)’
```

removes n bytes from the end of variable length object on the top of OS of given descriptor. The top variable length object is nullified if its length is less than n.

**Public function ‘top\_expand’**

```
‘void top_expand (size_t length)’
```

increases length of variable length object on the top of OS of given descriptor on number of bytes given as the parameter. The values of bytes added to the end of variable length object on the top of OS will be not defined.

**Public function ‘top\_add\_byte’**

```
‘void top_add_byte (int b)’
```

adds byte given as the parameter to the end of variable length object on the top of OS of given descriptor.

**Public function ‘top\_add\_memory’**

```
‘void top_add_memory (void *str, size_t length)’
```

adds memory starting with address given as the first parameter and with length given as the second parameter to the end of variable length object on the top of OS of given descriptor.

**Public function ‘top\_add\_string’**

```
‘void top_add_string (const char *str)’
```

adds C++ string (with end marker 0) given as the parameter to the end of variable length string on the top of OS of the descriptor. Before the addition the macro deletes last character of the top variable length object. The last character is suggested to be C++ string end marker 0.

## 5 Package for work with hash tables

The most compilers use search structures. Here the package ‘hashtab’ which implements expandable hash tables is suggested. This abstract data implements features analogous to ones of public domain functions ‘hsearch’, ‘hcreate’ and ‘hdestroy’. The goal of the abstract data creation is to implement additional needed features. The abstract data permits to work simultaneously with several expandable hash tables. Besides insertion and search of elements the elements from the hash tables can be also removed. The table element can be only a pointer. The size of hash tables is not fixed. The hash table will be expanded when its occupancy will become big.

The abstract data implementation is based on generalized Algorithm D from Knuth’s book "The art of computer programming". Hash table is expanded by creation of new hash table and transferring elements from the old table to the new table.

The package uses package ‘allocate’. The interface part of the abstract data is file ‘hashtab.h’. The implementation part is file ‘hashtab.cpp’. The interface contains the following objects:

**Type ‘hash\_table\_entry\_t’**

is described as ‘void \*’ and represents hash table element type. Empty entries have value ‘NULL’.

**Type ‘hash\_table\_t’**

describes hash table itself. The type is simply synonym of ‘class hash\_table \*’.

**Class ‘hash\_table’**

The class contains the following functions:

**Public constructor ‘hash\_table’**

```
‘hash_table
(size_t size,
 unsigned (*hash_function)
           (hash_table_entry_t el_ptr),
 int (*eq_function) (hash_table_entry_t el1_ptr,
                     hash_table_entry_t el2_ptr))’
```

creates hash table with length slightly longer than value of function parameter ‘size’. Created hash table is initiated as empty (all the hash table entries are NULL). The hash table will use functions ‘hash\_function’, ‘eq\_function’ given as the function parameters to evaluate table element hash value and function to test on equality of two table elements.



**Public destructor ‘hash\_table’**

```
‘~hash_table (void)’
```

deletes given hash table and frees memory allocated for it.

**Public function ‘empty’**

```
‘void empty (void)’
```

makes the hash table empty. If you need to remove all table elements, it is better to use this function than several times function ‘remove\_element\_from\_entry’. This function does not change size of the table or clear statistics about collisions.

**Public function ‘find\_entry’**

```
‘hash_table_entry_t *find_entry
    (hash_table_entry_t element,
     int reserve)’
```

searches for hash table entry which contains element equal to value of the function parameter ‘element’ or empty entry in which ‘element’ can be placed (if the element does not exist in the table). The function parameter ‘reserve’ is to be nonzero if the element is to be placed in the table. The element should be inserted into the table entry before another call of ‘find\_hash\_table\_entry’. The table is expanded if occupancy (taking into account also deleted elements) is more than 75%. The occupancy of the table after the expansion will be about 50%.

**Public function ‘remove\_element\_from\_entry’**

```
‘void remove_element_from_entry
    (hash_table_entry_t element)’
```

removes element from hash table\_entry whose value is given as the function parameter. Hash table entry for given value should be not empty (or deleted). The hash table entry value will be marked as deleted after the function call.

**Public function ‘size’**

```
‘size_t size (void)’
```

returns current size of given hash table.

**Public function ‘elements\_number’**

```
‘size_t elements_number (void)’
```

returns current number of elements in given hash table.

**Public function ‘collisions’**

```
‘int collisions (void)’
```

returns number of of percents of fixed collisions during all work with given hash table.

**Static public function ‘all\_collisions’**

```
‘int all_collisions (void)’
```

returns number of of percents of fixed collisions during all work with all hash tables.

## 6 Package for work with source code positions

The compilers often use internal representation which stores source code positions. Here package ‘position’ which serves to support information about source positions of compiled files taking into account all included files is suggested.

The strategy of the package usage can be follows. Function ‘initiate’ of class ‘positions’ is called by the first. After that function ‘start\_file’ of class ‘positions’ is called when a file is opened for compilation as source or included file. Members ‘line\_number’ and ‘column\_number’ of variable ‘current\_position’ are modified correspondingly during given file compilation. The value of ‘current\_position’ can be stored into internal representation for usage for output messages on the following passes. Function ‘finish\_file’ of class ‘positions’ is called when a processed file is closed. Function ‘finish’ of class ‘positions’ may be called after all processing a source file.

The package uses packages ‘vobject’ and ‘objstack’ which use package ‘allocate’. The interface part of the package is file ‘position.h’. The implementation part is file ‘position.cpp’. The interface contains the following objects:

### Type ‘position\_t’

is simply ‘class position’ describes a file position. The class has the following members:

#### Public members ‘line\_number’, ‘column\_number’

are source line and column corresponding to given position.

#### Public function ‘file\_name’

```
‘const char *file_name (void)’
```

returns name of file to which given position belongs.

#### Public function ‘path’

```
‘class position *path (void)’
```

is pointer to another position class object representing position of a include-clause which caused immediately given file compilation.

#### Public function ‘path’

```
‘int file_inclusion_level (void)’
```

returns number of level of position file inclusion. The level numbers are started with zero for positions corresponding non-included files and for positions which does not correspond to concrete file.

### Class ‘positions’

The class has not public constructors/destructors. The class has the following members:

#### Static const member ‘no\_position’

has value of type ‘position\_t’ has values ‘line\_number’, ‘column\_number’ equals to zero or ‘NULL’. The value does not correspond to concrete file position.

**Static member ‘current’**

has value which is current file position.

**Static public function ‘initiate’**

```
‘void initiate (void)’
```

initiates the package. Value of variable ‘current’ becomes equal to ‘no\_position’.

**Static public function ‘finish’**

```
‘void finish (void)’
```

frees all memory allocated during package work.

**Static public function ‘start\_file’**

```
‘void start_file (const char *file_name)’
```

save position in member variable ‘current’ and sets up new values of members of ‘current’. Values of members ‘file\_name’, ‘line\_number’, ‘column\_number’, and ‘path’ become equal to the function parameter value, 1, 0, and pointer to the saved position. Values of ‘current’ during different calls of the function must be different (e.g. different columns or lines), i.e. positions of different include-clauses must be different.

**Static public function ‘finish\_file’**

```
‘void finish_file (void)’
```

restores previous value of the member ‘current’, more exactly sets up the member by position to which the member ‘path’ refers.

**Static public Function ‘compare’**

```
‘int compare_positions (position_t position_1,  
                        position_t position_2)’
```

compares two positions given by parameters of type ‘position\_t’ and returns -1 (if the first position is less than the second), 0 (if the first position is equal to the second) or 1 (if the first position is greater than the second). The order of positions is lexicographic.

## 7 Package for output of compiler messages

The most of compilers report error messages for incorrect program. Here the package ‘errors’ which serves to output one-pass or multi-pass compiler messages of various modes (errors, warnings, fatal, system errors and appended messages) in Unix style or for traditional listing is suggested. The package also permits adequate error reporting for included files.

The package uses packages ‘vobject’, ‘objstack’, ‘position’ which use package ‘allocate’. Therefore package ‘position’ have to be initiated before any work with this package. The interface part of the package is file ‘errors.h’. The implementation part is file ‘errors.cpp’. The maximum length of generated error message is suggested to be not greater then ‘MAX\_ERROR\_MESSAGE\_LENGTH’. The default value (150) of this macro

can be redefined with corresponding C++ compiler option ‘-DMAX\_ERROR\_MESSAGE\_LENGTH=...’ during compilation of file ‘errors.cpp’. The interface contains only one class ‘errors’. The class has the following members:

**Public functions ‘number\_of\_errors’, ‘number\_of\_warnings’**

```
‘unsigned int number_of_errors (void)’  
‘unsigned int number_of_warnings (void)’
```

return values which are number of correspondingly errors and warnings fixed after given class object creation.

**Integer variable ‘maximum\_number\_of\_errors’**

has value which is maximum number of errors which will be fixed. If an error is fixed with number equals to ‘maximum\_number\_of\_errors’ then special fatal error ‘fatal error – too many errors’ with position of given error is fixed instead of the error. And all following errors are ignored. Zero value of the variable means that the special fatal error will never fixed.

**Public virtual function ‘fatal\_error\_function’**

```
‘void fatal_error_function (void)’
```

without parameters which will be called after fixing a fatal error. The fatal error function is suggested to do not return the control back. The default fatal error function only calls ‘exit (1)’.

**Public constructor ‘errors’**

```
‘errors (int immediate_output_flag)’
```

creates the class ‘errors’ object working in regime depending on parameter value. If the parameter value is nonzero than all fixed messages are output immediately. Otherwise the compiler messages are stored until function ‘output’ are called.

**Public destructor ‘errors’**

```
‘~errors (void)’
```

frees all memory allocated during the class ‘errors’ object work.

**Public function ‘output’**

```
‘void output (void)’
```

sorts (stable sorting) all fixed messages by their positions, outputs ones, and deletes ones. Appended messages will be output after corresponding error or warning. This function should be used only in regime of storing messages.

**Public function ‘error’**

```
‘void error (int fatal_error_flag, position_t
            position, const char *format, ...)’
```

fixes error (fatal error if the first parameter value is nonzero) at the position given as the second parameter. If the error is fatal than functions ‘output’ and ‘\*fatal\_error\_function’ are called. The diagnostic messages are formed analogous to output of function ‘printf’. For example,

```
error (1, current_position, "fatal error - no memory");
```

### Public function ‘warning’

```
‘void warning (position_t position, const char *format, ...)’
```

is analogous to the previous but is used to fix a warning.

### Public function ‘append\_message’

```
‘void append_message (position_t position,
                     const char *format, ...)’
```

When regime of immediately output of fixed message is on this function is analogous to the previous (except for incrementing ‘number\_of\_warnings’). In opposite case the appended message will be output with the most recent fixed error or warning independently from value of the first parameter. Of course the previously fixed error or warning must exist.

For example, this function may be used for generation of messages of type

```
‘<file>:<line>:<position-1>: repeated declaration’
```

and then

```
‘<file>:<line>:<position-1>: previous declaration’.
```

Description of function ‘output\_error\_function’ contains explanation why decremented position is output.

### Public function ‘system\_error’

```
‘void system_error (int fatal_error_flag,
                   position_t position,
                   const char *format, ...)’
```

is analogous to function ‘error’ but serves to fix a system error. The current system message without head blanks (given by standard function ‘strerror’) is placed after the message formed by the function parameters. For example, the following call may be used when a file is not opened

```
system_error (1, current_position,
              "fatal error - %s:", new_file_name);
```

**Public virtual function ‘output\_error\_function’**

```
‘void default_output_error_function
(int appended_message_flag, position_t position,
const char *message)’
```

is used to output error message. The function has three parameters – flag of appended message, message position and message itself.

By default the function is oriented to output in Unix style according to GNU standard. To output a listing the function ‘output\_error\_function’ should be changed. The default function output message in the following formats:

```
MESSAGE                                (NULL file name)
FILE_NAME:1: MESSAGE                  (zero line number)
FILE_NAME:LINE_NUMBER: MESSAGE        (zero column number)
FILE_NAME:LINE_NUMBER: COLUMN_NUMBER: MESSAGE (all other cases)
```

After that the function outputs newline. The function also outputs additional messages ‘in file processed from ...’ if given message is not appended message and corresponds to file different from one of previous output error. This message reflects path of the message position (see package ‘position’), i.e. reflects positions of corresponding include-clauses.

## 8 Package for work with command line

To make easy process of command line, here abstract data ‘commline’ is suggested. This abstract data implements features analogous to ones of public domain function ‘getopt’. The goal of the abstract data creation is to use more readable language of command line description and to use command line description as help output of program.

POSIX terminology concerning command line is used here. Command line is divided into command name and arguments. The arguments are subdivided into options, option-arguments and operands. Option starts with ‘-’. All arguments after first ‘-’ in command line are treated as operands.

The description of command line is made up from two parts. Any part (or both) may be absent in the description. First part contains option-arguments names of options which are in the second part. option-arguments names are separated by white space. The second part starts with percents ‘%%’ and contains any text in which description of options are placed. Any description of option starts with character “ followed by character ‘-’ and finishes by character ”. White spaces may precede option-argument name. It means that the corresponding option has obligatory separate option-argument. For example, the following may be a part of description of options of a pascal compiler command line.

---

```
dir xxx file
```

```
%%
```

```
command line: pc [options] file ...
```

```
Options:
```

```
‘-0’      Pascal standard level 0    ‘-1’      Pascal standard Level 1.
‘-29000’  Am29000 code generation    ‘-29050’* Am29050 code generation
```

---

'-c'	only object files creation	'-el'	output of listing
'-g'	information for debuggers	'-Idir'	data task units directory
'-lxxx'	library	'-Ldir'	libraries directory
'-o file'	output file	'-O'	all optimizations
'-S'	only ass. code creation	'-v'	loaded processes indication
'-w'	no warnings generation		
	Star * marks defaults		

---

In this example options with names '-I', '-l', '-L' and '-o' have option-arguments but only option with name '-o' has separate option-argument, i.e. option-argument which is represented by separate argument after given option in command line.

The interface part of the abstract data is file 'commline.h'. The package uses package 'vobject' which use package 'allocate'. The implementation part is file 'commline.cpp'. The interface contains only one class 'command\_line'. The class has the following members:

#### Public constructor 'command\_line'

```
'command_line (int argc, char **argv,
               const char *description,
               int &correct_description_flag)'
```

The constructor processes command line description given as string parameter and command line itself given as two parameter 'argc' and 'argv'. The function returns 0 through parameter 'correct\_description\_flag' if error in command line description is fixed, otherwise returns 1 (it means success).

#### Public destructor 'command\_line'

```
'~command_line (void)'
```

finishes work with the command line.

#### Public function 'output\_description'

```
'void output_description (void)'
```

outputs the second part (without '%%') of description of options to stderr. This function should be called when it is necessary to show the program usage.

#### Public function 'next\_operand'

```
'int next_operand (int flag_of_first)'
```

returns command line argument number of next operand if the function parameter is nonzero. Otherwise the function returns number of the first operand in the command line. The function returns 0 if all operands are already processed. Returned number may be used as index of array returned by function 'argument\_vector' to access corresponding operand.

**Public function ‘number\_of\_operands’**

```
‘int number_of_operands (void)’
```

returns number of operands in the command line.

**Public function ‘next\_option’**

```
‘int next_option (int flag_of_first)’
```

returns command line argument number of next option if the function parameter is nonzero. Otherwise the function returns number of the first option in the command line. The function returns 0 if all options are already processed. Returned number may be used as index of array returned by function ‘argument\_vector’ to access corresponding option.

**Function ‘option\_characteristics’**

```
‘char *option_characteristics (int argument_number,  
                               int *option_has_argument)’
```

returns pointer to option name which describes the command line argument with number ‘argument\_number’ given as the first parameter of the function. The function returns NULL if the corresponding option in the command line description is not found or an option described as with option-argument has not option-argument in the command line. Remember that option name with option-argument differs from option in the command line (e.g. ‘-U’ and ‘-Ufoo’). If the option in the command line description is found then the function sets up correspondingly the second function parameter ‘option\_has\_argument’. The case of returned NULL and ‘\*option\_has\_argument’ equals to TRUE means that given option must have option-argument but the option has not option-argument in the command line.

**Public function ‘last\_option\_place’**

```
‘int last_option_place (const char *option_name)’
```

returns number of last option with given option name in the command line. The function returns 0 if the option is absent in the command line.

**Public function ‘option\_argument’**

```
‘char *option_argument (const char *option_name)’
```

returns pointer to argument of last option in the command line with given option name. The function returns NULL if the option is absent in the command line. The function must be called only for options which have argument separated by white spaces.

**Public functions ‘argument\_count’, ‘argument\_vector’**



```

'int argument_count (void)'
'char **argument_vector (void)'

```

return 'argc' and 'argv' of function 'main'. See also description of the class constructor.

## 9 Package for work with bit strings

The package for work with bit strings is used to implement package 'IEEE'. But of course the package can be used for solving other tasks.

Here a bit is given by address (start address) of byte from which counting bits starts and its displacement which is any non negative number of bit from the start address. The most significant bit of the start address byte has number 0. The bit string is given by its first bit and its length in bits.

The interface part of the package is file 'bits.h'. The implementation part is file 'bits.cpp'. The interface contains only class 'bits' without public constructors and destructors. The class contains the following members:

### Static public function 'bit'

```

'int bit (const void *start_byte, int bit_displacement)'

```

returns given bit value as integer value '0' or '1'. There is static public function 'set\_bit'

```

'void set_bit (void *start_byte, int bit_displacement,
              int bit)

```

for changing value of a bit. Parameter 'bit' must have value '0' or '1'.

### Static public function 'is\_zero\_bit\_string'

```

'int is_zero_bit_string (const void *start_byte,
                        int bit_displacement,
                        int bit_length)'

```

returns '1' if given bit string contains only zero value bits, 0 otherwise.

### Static public function 'bit\_string\_set'

```

'void bit_string_set (void *start_byte, int
                    bit_displacement, int bit,
                    int bit_length)'

```

sets up new value of all bits of given bit string. This function is bit string analog of standard C++ function 'memset'.

### Static public function 'bit\_string\_copy'

```

void bit_string_copy (void *to, int to_bit_displacement,
                     const void *from,
                     int from_bit_displacement,
                     int bit_length)'

```

copies a bit string to another bit string. The bit strings must be nonoverlapped. This function is bit string analog of standard C++ function 'memcpy'.

#### Static public function 'bit\_string\_move'

```

void bit_string_move (void *to, int to_bit_displacement,
                     const void *from,
                     int from_bit_displacement,
                     int bit_length)'

```

copies a bit string to another bit string. The bit strings can be overlapped. This function is bit string analog of standard C++ function 'memmove'.

#### Static public function 'bit\_string\_comparison'

```

int bit_string_comparison
(const void *str1, int bit_displacement1,
 const void *str2, int bit_displacement2,
 int bit_length)'

```

returns 0 if the bit strings are equal, 1 if the first bit string is greater than the second, -1 if the first bit string is less than the second. This function is bit string analog of standard C++ function 'memcmp'.

## 10 Package for machine-independent arbitrary precision integer arithmetic

Abstract data 'arithm' may be used for implementation of a cross-compiler. This abstract data implements arbitrary precision integer and unsigned integer number arithmetic by machine independent way. The implementation of the package functions are not sufficiently efficient in order to use for run-time. The package functions are oriented to implement constant-folding in compilers. This package is necessary because host machine may not support such arithmetic for target machine. For example, VAX does not support more 32-bits integer numbers arithmetic.

The numbers in packages are represented by bytes in big endian mode, negative integer numbers are represented in complementary code. All sizes are given in bytes and must be positive. Results of executions of all functions can coincide with a operand(s). All functions of addition, subtraction, multiplication, division, evaluation of remainder, shift, changing size and transformation of string into number fix overflow. The overflow is fixed when result can not be represented by number of given size.

The interface part of the abstract data is file 'arithm.h'. The implementation part is file 'arithm.cpp'. The maximum length of integer number is suggested to be not greater than

‘MAX\_INTEGER\_OPERAND\_SIZE’. The default value (128) of this macro can be redefined with corresponding C++ compiler option ‘-DMAX\_INTEGER\_OPERAND\_SIZE=...’ during compilation of file ‘arithm.cpp’. But in any case the minimal value of the macros will be 16. The interface contains the following external definitions:

### Class ‘integer’

is auxiliary. It serves to describe common variables and functions for work with signed and unsigned integers (classes ‘signed\_integer’ and ‘unsigned\_integer’). The class ‘integer’ has the following members.

#### Public static variable ‘overflow\_bit’

has only two values 0 or 1. The value ‘1’ corresponds to overflow. The variable value are modified by all functions of addition, subtract, multiplication, division, evaluation of remainder, shift, changing size and transformation of string into number.

#### Public static variable ‘const unsigned char \*zero\_constant’

represents zero (unsigned) integer of any size.

#### Public static function ‘default\_arithmetic\_overflow\_reaction’

```
‘void default_arithmetic_overflow_reaction (void)’
```

Originally reaction on all integer and unsigned integer overflow is equal to this function. The function does nothing. Reaction on overflow for integers or unsigned integers is called after setting up variable ‘overflow\_bit’.

### Classes ‘signed\_integer’ and ‘unsigned\_integer’

are sub-classes of the class ‘integer’. The first class contains functions for implementation of signed integer arithmetic. The second one contains functions for implementation of unsigned integer arithmetic. The classes contains the following functions:

#### Static public function ‘set\_overflow\_reaction’

```
‘void (*set_overflow_reaction
      (void (*function) (void))) (void)’
```

change reaction on integer overflow and returns previous overflow reaction function.

#### Static public functions ‘maximum’

```
‘void maximum (int size, void *result)’
```

create given size (in bytes) maximal integer constant which is placed in memory whose address is given by the second parameter.

#### Static public functions ‘add’

```
‘void add (int size, const void *op1,
          const void *op2,
          void *result)’
```

make integer addition of integers of given size. The functions fix overflow when result can not be represented by number of given size. There are analogous functions which implement other operations:

```

    'subtract',
    'multiply',
    'divide',
    'remainder'.

```

#### Static public functions 'shift\_left'

```

    'void shift_left (int size, const void *operand,
                     int bits, void *result)'

```

make left shift of integer of given size on given number of bits. If number of bits is negative the functions make shift to right actually. The functions fix overflow when result can not be represented by number of given size, i.e. in other words the opposite shift (to right) results in number not equal to source operand. There are analogous functions which implement another operation

```

    'shift_right'.

```

#### Static public function '\_or\_'

```

    'void _or_ (int size, const void *op1,
               const void *op2,
               void *result)'

```

make bitwise 'or' of integers of given size. There are analogous functions which implement bitwise 'and' and 'xor':

```

    '_and_',
    '_xor_'.

```

Static public functions

```

    'void _not_ (int size, const void *operand,
                void *result)'

```

make bitwise 'not' of integer of given size.

#### Static public functions 'eq'

```

    'int eq (int size, const void *op1, const void *op2)'

```

compare two integers of given size on equality and returns 1 or 0 depending on result of the comparison. There are analogous functions which implement other integer operations:

```

    'ne',
    'gt',
    'lt',
    'ge',
    and 'le'.

```

#### Static public functions 'change\_size'

```

void change_size (int operand_size,
                  const void *operand,
                  int result_size, void *result)'

```

change size of integer. The functions fix overflow when result can not be represented by number of given size.

#### Static public functions 'to\_string'

```

char *to_string (int size, const void *operand,
                 char *result)'

```

transform integer of given size to decimal ascii representation. Sign is present in result string only for negative numbers (it is not possible for the function in class 'unsigned\_integer'). The functions return value 'result'.

#### Static public functions 'to\_based\_string'

```

char *to_based_string (int size, const void *operand,
                       int base, char *result)'

```

transform integer of given size to ascii representation with given base. The base should be between 2 and 36 including them. Digits more 9 are represented by 'a', 'b' etc. Sign is present in result string only for negative numbers (it is not possible for the function in class 'unsigned\_integer'). The functions return value 'result'.

#### Static public functions 'from\_string'

```

char *from_string (int size, const char *operand,
                   void *result)'

```

skip all white spaces at the begin of source string and transforms the tail of the source string (decimal ascii representation with possible sign '+' or '-' only for the function in class 'signed\_integer') to given size integer and return pointer to first non digit in the source string. If the string started with invalid integer representation the result will be zero. The functions fix overflow when result can not be represented by number of given size.

#### Static public functions 'from\_based\_string'

```

char *from_based_string (int size, const char *operand,
                         int base, void *result)'

```

skip all white spaces at the begin of source string and transforms the tail of the source string (ascii representation with given base and with possible sign '+' or '-' only for the function in class 'signed\_integer') to given size integer and return pointer to first non digit in the source string. The base should be between 2 and 36 including them. Digits more 9 are represented by 'a' (or 'A'), 'b' (or 'B') etc. If the string started with invalid integer representation the result will be zero. The functions fix overflow when result can not be represented by number of given size.

#### Classes 'sint' and 'unsint'

Classes 'signed\_integer' and 'unsigned\_integer' containing only static function are simply written in C style. Object oriented implementation of integer arithmetic requires C++ template classes which is

not supported all C++ compilers. Therefore if you define macro 'NO\_TEMPLATE' before inclusion of interface file, classes 'sint' and 'unsint' will be absent. The classes is parameterized by size of integers (in bytes). As the classes are subclasses of 'signed\_integer' and 'unsigned\_integer', you can members 'overflow\_bit', 'set\_overflow\_reaction' to work with arithmetic overflow. The classes have the following members:

#### Public constructors 'sint', 'unsint'

```
'sint (int value)', 'sint (void)'
'unsint (unsigned int value)', 'unsint (void)'
```

can be used for creation integer with given value or zero integer.

#### Static public functions 'max', 'min'

```
'class sint<size> max (void)'
'class sint<size> min (void)'
'class unsint<size> max (void)'
'class unsint<size> min (void)'
```

create integers and unsigned integers of maximal and minimal value.

#### Public operators '+'

```
'class sint<size> operator +
    (const class sint<size> &op)'
'class unsint<size> operator +
    (const class unsint<size> &op)'
```

make integer addition of integers of given size. The operator fixes overflow when result can not be represented by number of given size. There are analogous operators which implement other operations:

```
'-',
'*',
/',
'%'.

```

#### Public operators '<<'

```
'class sint<size> operator << (int bits)'
'class unsint<size> operator << (int bits)'
```

make left shift of integer on given number of bits. If number of bits is negative operator makes shift to right actually. The operators fix overflow when result can not be represented by number of given size, i.e. in other words the opposite shift (to right) results in number not equal to source operand. There are analogous operators which implement another operation (right shift)

```
'>>'.

```

#### Public operators '|'

```

class sint<size> operator |
    (const class sint<size> &op)'
class unsint<size> operator |
    (const class unsint<size> &op)'

```

make bitwise ‘or’ of integers. There are analogous operators which implement bitwise ‘and’ and ‘xor’:

```

'&',
'^'.

```

Public operators

```

class sint<size> operator ~ (void)'
class unsint<size> operator ~ (void)'

```

make bitwise ‘not’ of integer of given size.

**Public operators ‘==’**

```

int operator == (const class sint<size> &op)'
int operator == (const class unsint<size> &op)'

```

compare two integers of given size on equality and returns 1 or 0 depending on result of the comparison. There are analogous operators which implement other integer operations:

```

'!=',
'>',
'<',
'>=',
and '<='.

```

**Public functions ‘to\_str’**

```

char *to_str (char *result)'

```

transform integer to decimal ascii representation. Sign is present in result string only for negative numbers (it is not possible for the function in class ‘unsint’). The functions return value ‘result’.

**Public functions ‘to\_based\_str’**

```

char *to_based_str (int base, char *result)'

```

transform integer to ascii representation with given base. The base should be between 2 and 36 including them. Digits more 9 are represented by ‘a’, ‘b’ etc. Sign is present in result string only for negative numbers (it is not possible for the function in class ‘unsint’). The functions return value ‘result’.

**Public functions ‘from\_str’**

```

char *from_str (const char *operand)'

```

skip all white spaces at the begin of source string and transforms the tail of the source string (decimal ascii representation with possible sign '+' or '-' only for the function in class 'signed\_integer') to given integer and return pointer to first non digit in the source string. If the string started with invalid integer representation the result will be zero. The functions fix overflow when result can not be represented by number of given size.

#### Public functions 'from\_based\_str'

```
'char *from_based_str (const char *operand, int base)'
```

skip all white spaces at the begin of source string and transforms the tail of the source string (ascii representation with given base and with possible sign '+' or '-' only for the function in class 'signed\_integer') to given integer and return pointer to first non digit in the source string. The base should be between 2 and 36 including them. Digits more 9 are represented by 'a' (or 'A'), 'b' (or 'B') etc. If the string started with invalid integer representation the result will be zero. The functions fix overflow when result can not be represented by number of given size.

#### Template functions 'new\_size'

```
'template <int result_size, int operand_size>
inline void new_size (class sint<operand_size> &operand,
                     class sint<result_size> &result)'
'template <int result_size, int operand_size>
inline void new_size (class unsint<operand_size> &operand,
                     class unsint<result_size> &result)'
```

change size of integer. The functions fix overflow when result can not be represented by number of given size.

## 11 Package for machine-independent IEEE floating point arithmetic

Abstract data 'IEEE' may be used for implementation of a cross-compiler. This abstract data implements IEEE floating point arithmetic by machine independent way with the aid of package 'arithm'. This abstract data is necessary because host machine may not support such arithmetic for target machine. For example, VAX does not support IEEE floating point arithmetic. The floating point numbers are represented by bytes in big endian mode. The implementation of the package functions are not sufficiently efficient in order to use for run-time. The package functions are oriented to implement constant-folding in compilers. All integer sizes (see transformation functions) are given in bytes and must be positive.

Functions of addition, subtraction, multiplication, division, conversion of floating point numbers of different formats can fix input exceptions. If an operand of such operation is trapping (signal) not a number then invalid operation and reserved operand exceptions are fixed and the result is (quiet) NaN, otherwise if an operand is (quiet) NaN then only reserved operand exception is fixed and the result is (quiet) NaN. Operation specific processing the rest of special case values of operands is placed with description of the operation. In general case the function can fix output exceptions and produces results for exception according to the following table. The result and status for a given exceptional operation are determined by the highest priority exception. If, for example, an operation produces both overflow and imprecise result exceptions, the overflow



exception, having higher priority, determines the behavior of the operation. The behavior of this operation is therefore described by the Overflow entry of the table.

Exception	Condition	Result	Status
Overflow	masked	IEEE_RN(_RP)	+Inf  IEEE_OFL and
	overflow   sign +	IEEE_RZ(_RM)	+Max  IEEE_IMP
	exception		
	sign -	IEEE_RN(_RM)	-Inf  IEEE_OFL and
		IEEE_RZ(_RP)	-Max  IEEE_IMP
	unmasked	Precise result	See  IEEE_OFL
	overflow		above
	exception	Imprecise result	IEEE_OFL and
Underflow			IEEE_IMP
	masked		Rounded IEEE_UFL and
	underflow	Imprecise result	result  IEEE_IMP
	exception		
	unmasked	Precise result	result  IEEE_UFL
	underflow		
	exception	Imprecise result	Rounded IEEE_UFL and
			result  IEEE_IMP
Imprecise	masked imprecise exception	Rounded	IEEE_IMP
		result	
	unmasked imprecise exception	Rounded	IEEE_IMP
		result	

The package uses package 'bits'. The interface part of the abstract data is file 'IEEE.h'. The implementation part is file 'IEEE.cpp'. The interface contains the following external definitions:

Macros 'IEEE\_FLOAT\_SIZE', 'IEEE\_DOUBLE\_SIZE', 'IEEE\_QUAD\_SIZE'

have values which are sizes of IEEE single, double and quad precision floating point numbers ('4', '8', and '16' correspondingly).

Macros 'MAX\_SINGLE\_10\_STRING\_LENGTH', 'MAX\_DOUBLE\_10\_STRING\_LENGTH', 'MAX\_QUAD\_10\_STRING\_LENGTH'

have values which are maximal length of string generated by functions creating decimal ascii representation of IEEE floats (see functions to\_string).

Macros 'MAX\_SINGLE\_16\_STRING\_LENGTH', 'MAX\_DOUBLE\_16\_STRING\_LENGTH', 'MAX\_QUAD\_16\_STRING\_LENGTH'

have values which are maximal length of string generated by functions creating binary ascii representation of IEEE floats with given base (see functions to\_binary\_string).

Types 'IEEE\_float\_t', 'IEEE\_double\_t', and 'IEEE\_quad\_t'

are simply synonyms of classes ‘IEEE\_float’, ‘IEEE\_double’, and ‘IEEE\_quad’ representing correspondingly IEEE single precision, double, and quad precision floating point numbers.

#### Constants ‘IEEE\_RN’, ‘IEEE\_RM’, ‘IEEE\_RP’, ‘IEEE\_RZ’

defines rounding control (round to nearest representable number, round toward minus infinity, round toward plus infinity, round toward zero).

Round to nearest means the result produced is the representable value nearest to the infinitely-precise result. There are special cases when infinitely precise result falls exactly halfway between two representable values. In this cases the result will be whichever of those two representable values has a fractional part whose least significant bit is zero.

Round toward minus infinity means the result produced is the representable value closest to but no greater than the infinitely precise result.

Round toward plus infinity means the result produced is the representable value closest to but no less than the infinitely precise result.

Round toward zero, i.e. the result produced is the representable value closest to but no greater in magnitude than the infinitely precise result.

#### Class ‘IEEE’

The class has the following functions common for all packages:

##### Static public function ‘reset’

```
‘void reset (void)’
```

and to separate bits in mask returned by functions

```
‘IEEE_get_sticky_status_bits’,  
‘IEEE_get_status_bits’, and  
‘IEEE_get_trap_mask’.
```

##### Function ‘IEEE\_reset’

```
‘void IEEE_reset (void)’
```

and to separate bits in mask returned by functions

```
‘IEEE_get_sticky_status_bits’,  
‘IEEE_get_status_bits’, and  
‘IEEE_get_trap_mask’.
```

##### Static public function ‘get\_trap\_mask’

```
‘int get_trap_mask (void)’
```

returns exceptions trap mask. Static public function

```
‘int set_trap_mask (int mask)’
```

sets up new exception trap mask and returns the previous.

If the mask bit corresponding given exception is set, a floating point exception trap does not occur for given exception. Such exception is said to be masked exception. Initial exception trap mask is zero. Remember that more one exception may be occurred simultaneously.

**Static public function ‘set\_sticky\_status\_bits’**

```
‘int set_sticky_status_bits (int mask)’
```

changes sticky status bits and returns the previous bits.

Static public function

```
‘int get_sticky_status_bits (void)’
```

returns mask of current sticky status bits. Only sticky status bits corresponding to masked exceptions are updated regardless whether a floating point exception trap is taken or not. Initial values of sticky status bits are zero.

**Static public function ‘get\_status\_bits’**

```
‘int get_status_bits (void)’
```

returns mask of status bits. It is supposed that the function will be used in trap on an floating point exception. Status bits are updated regardless of the current exception trap mask only when a floating point exception trap is taken. Initial values of status bits are zero.

**Static public functions ‘set\_round’, ‘get\_round’**

```
‘int set_round (int round_mode)’
```

which sets up current rounding mode and returns previous mode and

```
‘int IEEE_get_round (void)’
```

which returns current mode. Initial rounding mode is round to nearest.

**Static public function ‘default\_floating\_point\_exception\_trap’**

```
‘void default_floating_point_exception_trap (void)’
```

Originally reaction on occurred trap on an unmasked floating point exception is equal to this function. The function does nothing. All occurred exceptions can be found in the trap with the aid of status bits.

**Static public function ‘set\_floating\_point\_exception\_trap’**

```
‘void (*set_floating_point_exception_trap  
      (void (*function) (void))) (void)’
```

sets up trap on an unmasked exception. Function given as parameter simulates floating point exception trap.

**Classes ‘IEEE\_float’, ‘IEEE\_double’, and ‘IEEE\_quad’**

The classes implements IEEE floating point numbers in object-oriented style. The following functions are described for class ‘IEEE\_float’. The classes ‘IEEE\_double’ and ‘IEEE\_quad’ have analogous functions (if details are absent) with the same names but for IEEE double and quad numbers.

**Public constructors ‘IEEE\_float’, ‘IEEE\_double’, ‘IEEE\_quad’**

```

'IEEE_float (void)'
'IEEE_float (float f)'
'IEEE_double (void)'
'IEEE_double (float f)'
'IEEE_quad (void)'
'IEEE_quad (float f)'

```

creates IEEE single, IEEE double, or IEEE quad precision numbers with positive zero values or with given value.

**Public function 'positive\_zero'**

```

'void positive_zero (void)'

```

Given float becomes positive single precision zero constant. There are analogous functions which return other special case values:

```

'negative_zero',
'NaN',
'trapping_NaN',
'positive_infinity',
'negative_infinity',

```

According to the IEEE standard NaN (and trapping NaN) can be represented by more one bit string. But all functions of the package generate and use only one its representation created by function 'NaN' (and 'trapping\_NaN'). A (quiet) NaN does not cause an Invalid Operation exception and can be reported as an operation result. A trapping NaN causes an Invalid Operation exception if used as in input operand to floating point operation. Trapping NaN can not be reported as an operation result.

**Public function 'is\_positive\_zero'**

```

'int is_positive_zero (void)'

```

returns 1 if given number is positive single precision zero constant. There are analogous functions for other special case values:

```

'is_negative_zero',
'is_NaN',
'is_trapping_NaN',
'is_positive_infinity',
'is_negative_infinity',
'is_positive_maximum' (positive max value),
'is_negative_maximum',
'is_positive_minimum' (positive min value),
'is_negative_minimum',

```

In spite of that all functions of the package generate and use only one its representation created by function 'NaN' (or 'trapping\_NaN'). The function 'is\_NaN' (and 'trapping\_NaN') determines any representation of NaN.

**Public function 'is\_normalized'**

```
‘int is_normalized (void)’
```

returns TRUE if given number is normalized (special case values are not normalized). There is analogous function

```
‘is_denormalized’
```

for determination of denormalized number.

**Public operator ‘+’**

```
‘class IEEE_float operator + (class IEEE_float &op)’
```

makes single precision addition of floating point numbers. There are analogous operators which implement other floating point operations:

```
‘-’,
‘*’,
‘/’,
```

Results and input exceptions for operands of special cases values (except for NaNs) are described for addition by the following table

first operand	second operand		
	+Inf	-Inf	Others
+Inf	+Inf	NaN	+Inf
	none	IEEE_INV(_RO)	none
-Inf	NaN	-Inf	-Inf
	IEEE_INV(_RO)	none	none
Others	+Inf	-Inf	
	none	none	

Results and input exceptions for operands of special cases values (except for NaNs) are described for subtraction by the following table

first operand	second operand		
	+Inf	-Inf	Others
+Inf	NaN	+Inf	+Inf
	IEEE_INV(_RO)	none	none
-Inf	-Inf	NaN	-Inf
	none	IEEE_INV(_RO)	none
Others	-Inf	+Inf	
	none	none	

Results and input exceptions for operands of special cases values (except for NaNs) are described for multiplication by the following table

first operand	second operand			
	+Inf	-Inf	0	Others
+Inf	+Inf none	-Inf none	NaN IEEE_INV (_RO)	(+-)Inf none
-Inf	-Inf none	+Inf none	NaN IEEE_INV (_RO)	(+-)Inf none
0	NaN IEEE_INV (_RO)	NaN IEEE_INV (_RO)	(+-)0 none	(+-)0 none
Others	(+-)Inf none	(+-)Inf none	(+-)0 none	

Results and input exceptions for operands of special cases values (except for NaNs) are described for division by the following table

first operand	second operand			
	+Inf	-Inf	0	Others
+Inf	NaN IEEE_INV (_RO)	NaN IEEE_INV (_RO)	(+-)Inf none	(+-)Inf none
-Inf	NaN IEEE_INV (_RO)	NaN IEEE_INV (_RO)	(+-)Inf none	(+-)Inf none
0	(+-)0 none	(+-)0 none	NaN IEEE_INV (_RO)	(+-)0 none
Others	(+-)0 none	(+-)0 none	(+-)Inf IEEE_DZ	

#### Public operator ‘==’

```
‘int operator == (class IEEE_float &op)’
```

compares two floating point numbers on equality and returns 1 or 0 depending on result of the comparison. There are analogous operators which implement other integer operations:

```
‘!=’,
```

```

'>',
'>=',
'<',
'<='.

```

Results and input exceptions for operands of special cases values are described for equality and inequality by the following table

first operand	second operand		
	SNaN	QNaN	Others
SNaN	FALSE IEEE_INV	FALSE IEEE_INV	FALSE IEEE_INV
QNaN	FALSE IEEE_INV	FALSE none	FALSE none
Others	FALSE IEEE_INV	FALSE none	

Results and input exceptions for operands of special cases values are described for other comparison operation by the following table

first operand	second operand		
	SNaN	QNaN	Others
SNaN	FALSE IEEE_INV	FALSE IEEE_INV	FALSE IEEE_INV
QNaN	FALSE IEEE_INV	FALSE IEEE_INV	FALSE IEEE_INV
Others	FALSE IEEE_INV	FALSE IEEE_INV	

#### Public functions 'to\_string'

```
'char *to_string (char *result)'
```

transform single precision to decimal ascii representation with obligatory integer part (1 digit), fractional part (of constant length), and optional exponent. Signs minus are present if it is needed. The special cases IEEE floating point values are represented by strings 'SNaN', 'QNaN', '+Inf', '-Inf', '+0', and '-0'. The functions return value 'result'. Current round mode does not affect the resultant ascii representation. The functions output 9 decimal fraction digits for single precision number, 17 decimal fraction digits for double precision number, and 36 decimal fraction digits for quad precision number

#### Public functions 'to\_binary\_string'

```
'char *to_binary_string (int base, char *result)'
```

The functions are analogous to `to_string` but transform float number into to binary ascii representation with obligatory integer part (1 digit) of given base, optional fractional part of given base, and optional binary exponent (decimal number giving power of 2). The binary exponent starts with character 'p' instead of 'e'. Signs minus are present if it is needed. The special cases IEEE floating point values are represented by strings 'SNaN', 'QNaN', '+Inf', '-Inf', '+0', and '-0'. The functions return value 'result'. Value of parameter base should be 2, 4, 8, or 16. Current round mode does not affect the resultant ascii representation.

#### Public functions 'from\_string'

```
'char *from_string (const char *operand)'
```

skip all white spaces at the begin of source string and transforms tail of the source string to single precision floating point number. The number must correspond the following syntax

```
[ '+' | '-' ] [<decimal digits>]
[ '.' [<decimal digits>] ]
[ ('e' | 'E') [ '+' | '-' ] <decimal digits>]
```

or must be the following strings 'SNaN', 'QNaN', '+Inf', '-Inf', '+0', or '-0'. The functions return pointer to first character in the source string after read floating point number. If the string does not correspond floating point number syntax the result will be zero and functions return the source string.

The functions can fix output exceptions as described above. Current round mode may affect resultant floating point number. It is guaranteed that transformation 'IEEE floating point number -> string -> IEEE floating point number' results in the same IEEE floating point number if round to nearest mode is used. But the reverse transformation 'string with 9 (or 17) digits -> IEEE floating point number -> string' may results in different digits of the fractions in ascii representation because a floating point number may represent several such strings with differences in the least significant digit. But the ascii representations are identical when the functions for IEEE single, double, and quad precision numbers do not fix imprecise result exception or less than 9 (17 or 36) digits of the fractions in the ascii representations are compared.

#### Public functions 'from\_binary\_string'

```
'char *from_binary_string (const char *operand, int base)'
```

The functions are analogous to `to_string` but transform binary representation of the floating point number. The number must correspond the following syntax

```
[ '+' | '-' ] [<digits less base>] [ '.' [<digits less base>] ]
[ ('p' | 'P') [ '+' | '-' ] <decimal digits>]
```

or must be the following strings 'SNaN', 'QNaN', '+Inf', '-Inf', '+0', or '-0'. The functions return pointer to first character in the source string after read floating point number. If the string does not correspond floating point number syntax the result will be zero and function returns the source string. The exponent (after character 'p' or 'P') defines power of two.

The functions can fix output exceptions as described above. Current round mode can affect resultant floating point number if there are too many given digits.



**Public transformation functions**

In class 'IEEE\_float'

```
'class IEEE_double to_double (void)'
'class IEEE_quad to_quad (void)'
'class IEEE_float &from_signed_integer
    (int size, const void *integer)'
'class IEEE_float &from_unsigned_integer
    (int size,
     const void *unsigned_integer)'
'void to_signed_integer (int size, void *integer)'
'void to_unsigned_integer (int size,
    void *unsigned_integer)'
```

In class 'IEEE\_double'

```
'class IEEE_float to_single (void)'
'class IEEE_quad to_quad (void)'
'class IEEE_double &from_signed_integer
    (int size,
     const void *integer)'
'class IEEE_double &from_unsigned_integer
    (int size,
     const void *unsigned_integer)'
'void to_signed_integer (int size, void *integer)'
'void to_unsigned_integer (int size,
    void *unsigned_integer)'
```

In class 'IEEE\_quad'

```
'class IEEE_float to_single (void)'
'class IEEE_double to_double (void)'
'class IEEE_quad &from_signed_integer
    (int size,
     const void *integer)'
'class IEEE_quad &from_unsigned_integer
    (int size,
     const void *unsigned_integer)'
'void to_signed_integer (int size, void *integer)'
'void to_unsigned_integer (int size,
    void *unsigned_integer)'
```

Actually no one output exceptions occur during transformation of single precision floating point number to double (or quad) precision number and of double precision floating point number to quad precision number. No input exceptions occur during transformation of integer numbers to floating point numbers. Results and input exceptions for operand of special cases values (and for NaNs) are described for conversion floating point number to integer by the following table

Operand	Result & Exception
-----	-----
SNaN	0
	IEEE_INV(_RO)

-----	-----
QNaN	0
	IEEE_INV(_RO)
-----	-----
+Inf	IMax
	IEEE_INV
-----	-----
-Inf	IMin
	IEEE_INV
-----	-----
Others	

Results and input exceptions for operand of special cases values (and for NaNs) are described for conversion floating point number to unsigned integer by the following table

Operand	Result & Exception
-----	-----
SNaN	0
	IEEE_INV(_RO)
-----	-----
QNaN	0
	IEEE_INV(_RO)
-----	-----
+Inf	IMax
	IEEE_INV
-----	-----
-Inf or negative number	0
	IEEE_INV
-----	-----
Others	

Results and exceptions for NaNs during transformation of floating point numbers to (unsigned) integers are differed from the ones for operations of addition, multiplication and so on.

### Template transformation functions

As mentioned above there are template classes 'sint' and 'unsint' of package 'arithm'. Therefore package 'IEEE' contains template functions for transformation of between IEEE numbers and integer numbers. As in package 'arithm' if you define macro 'NO\_TEMPLATE' before inclusion of interface file, these template transformation functions will be absent. There are the following functions:

```

template <int size>
class IEEE_float &IEEE_float_from_unsint
    (class IEEE_float &single,
     class unsint<size> &unsigned_integer)'

template <int size>
class IEEE_float &IEEE_float_from_sint
    (class IEEE_float &single,
     class sint<size> &integer)

```

```

template <int size>
void IEEE_float_to_sint (class IEEE_float &single,
                        class sint<size> &integer)'

template <int size>
void IEEE_float_to_unsint
    (class IEEE_float &single,
     class unsint<size> &unsigned_integer)'

template <int size>
class IEEE_double &IEEE_double_from_unsint
    (class IEEE_double &single,
     class unsint<size> &unsigned_integer)'

template <int size>
class IEEE_double &IEEE_double_from_sint
    (class IEEE_double &single,
     class sint<size> &integer)

template <int size>
void IEEE_double_to_sint (class IEEE_double &single,
                        class sint<size> &integer)'

template <int size>
void IEEE_double_to_unsint
    (class IEEE_double &single,
     class unsint<size> &unsigned_integer)'

template <int size>
class IEEE_quad &IEEE_quad_from_unsint
    (class IEEE_quad &single,
     class unsint<size> &unsigned_integer)'

template <int size>
class IEEE_quad &IEEE_quad_from_sint
    (class IEEE_quad &single,
     class sint<size> &integer)

template <int size>
void IEEE_quad_to_sint (class IEEE_quad &single,
                      class sint<size> &integer)'

template <int size>
void IEEE_quad_to_unsint
    (class IEEE_quad &single,
     class unsint<size> &unsigned_integer)'

```

Exceptions for these functions are the same as described above for functions 'from\_signed\_integer', 'to\_signed\_integer' and so on.

Important note: All items (they contains word quad or QUAD in their names) relative to IEEE 128 bits floating point numbers are defined only when macro 'IEEE\_QUAD' is defined. By default 'IEEE\_QUAD' is not defined. It is made because supporting IEEE 18-bits numbers requires more 100Kb memory.

## 12 Ticker package

The package ‘ticker’ implements a timer. Timer can be activated or can be stopped. The timer accumulates execution time only when it is in active state. The interface part of the package is file ‘ticker.h’. The implementation part is file ‘ticker.cpp’. The interface contains the following external definitions and macros:

### Type ‘ticker\_t’

describes a timer. This type is simply synonym of ‘class ticker’.

### Class ‘ticker’

Timers are objects of this class. The class has the following members:

#### Public constructor ‘ticker’

```
‘ticker (void)’
```

creates new timer. The state of the timer is active.

#### Public function ‘ticker\_off’

```
‘void ticker_off (void)’
```

stops given timer.

#### Public function ‘ticker\_on’

```
‘void ticker_on (void)’
```

activates given timer.

#### Function ‘active\_time’

```
‘double active_time (ticker_t ticker)’
```

returns time in seconds as double float value in which the timer given as the function parameter was active.

#### Function ‘active\_time\_string’

```
‘const char *active_time_string (ticker_t ticker)’
```

returns string representation of time in seconds in which the timer given as the function parameter was active. Remember that this function must be the single in a C++ expression because the string is stored in a static variable of the function.

## 13 Expandable sparse set

The package ‘bits’ can be used to represent sets. In many applications (e.g. in compiler optimizations) sets are sparse for all possible elements values. The package ‘spset’ implements sparse sets described in "An Efficient Representation for Sparse Sets" by Preston Briggs and Linda Torczon. The sparse set implementation has the following features:

- It is fast. It has complexity  $O(1)$  for testing, insertion, remove of the element and  $O(n)$  for union, intersection, difference, comparison, and traverse of the sets, where 'n' is number of elements in the set.
- The set has a size. Elements with values less than size can be stored in the set. The memory is needed for the set representation is  $O(\text{size})$ .
- When the element is inserted and does not fit into the set, the set is automatically extended to store the element and may be elements with even bigger values.

The interface part of the sparse set is file 'spset.h'. The implementation part is file 'spset.cpp'. The interface contains the following external definitions and macros:

#### Type 'spset\_elem\_t'

is an unsigned integer type representing the set element.

#### Macro 'SPSET\_MAX\_ELEM'

is a maximal possible value of the previous type.

#### Class 'spset'

The class contains the following functions:

##### Public constructor 'spset'

```
'spset (spset_elem_t size = 0)'
```

creates set with initial size close to 'size' but not less than it. With default parameter value the minimal size set is created.

##### Public destructor ' ~spset'

```
'~spset (void)'
```

deletes given set and frees memory allocated for it.

##### Public member function 'size'

```
'spset_elem_t size (void)'
```

returns the current size of the set. Elements with values less than the size can be inserted without an expansion.

##### Public member function 'cardinality'

```
'spset_elem_t cardinality (void)'
```

returns number of elements containing currently in the set.

##### Public member function 'copy'

```
'void copy (spset *from)'
```

copies value of set 'from' to given set.

**Public member function ‘swap’**

```
‘void swap (spset *s)’
```

swaps values of given set and ‘s’.

**Public member function ‘in\_p’**

```
‘int in_p (spset_elem_t el)’
```

returns TRUE if the set contains element ‘el’.

**Public member function ‘insert’**

```
‘int insert (spset_elem_t el)’
```

inserts element ‘el’ into the set. Return TRUE if the set has been changed, in other words, it did not contain the element. If the set size is not enough to contain the element, the set is expanded.

**Public member function ‘remove’**

```
‘int remove (spset_elem_t el)’
```

removes element ‘el’ from the set. Return TRUE if the set has been changed, in other words, it really contained the element.

**Public member function ‘clear’**

```
‘int clear (void)’
```

removes all elements from the set. Return TRUE if the set has been changed, in other words, it was not empty.

**Public member function ‘equal\_p’**

```
‘int equal_p (spset *s)’
```

returns TRUE if given set and ‘s’ contain exactly the same elements.

**Public member function ‘intersect’**

```
‘int intersect (spset *s)’
```

removes elements in given set which are not in set ‘s’. Returns TRUE if the set has been changed, in other words, if given set or ‘s’ had any non-common elements.

**Public member function ‘unity’**

```
‘int unity (spset *s)’
```

adds all elements of set ‘s’ to given set. Returns TRUE if the set has been changed, in other words, if any new element was added to given set. The set can be automatically expanded if it is necessary.

**Public member function ‘diff’**

```
‘int intersect (spset *s)’
```

removes all elements of set ‘s’ from given set. Returns TRUE if the set has been changed, in order words, if given set and ‘s’ had any common elements.

**Public member function ‘shrink’**

```
‘void shrink (void)’
```

decreases size of the set if it is possible. During set life, the set can be automatically expanded but it is never automatically shrunk. After some element removes, it might be possible to shrink set size to save memory. The function serves this purpose.

**Public static function ‘release\_unused\_memory’**

```
‘void release_unused_memory (void)’
```

releases internal memory pool. The pool is used to speed up size changing of sets. It is wise to call the function when you finish to work with all sets.

**Public member function ‘print’**

```
‘void print (FILE *f)’
```

prints all elements of the set into file ‘f’.

**Public member function ‘debug’**

```
‘void debug (void)’
```

prints all elements of the set into stderr.

**Class ‘spset\_iterator’**

is used to define iterators for traverses of sets (see the macro below).

**Macro ‘EXECUTE\_FOR\_EACH\_SPSET\_ELEM’**

```
‘EXECUTE_FOR_EACH_SPSET_ELEM (SET, EL, SI) c++-stmt’
```

executes ‘c++-stmt’ for each element of ‘SET’. During execution, the current element value is assigned to ‘EL’. You need to declare somewhere and use iterator ‘SI’ in the macro call. The order of traverse of the set elements is undefined. The traverse behaviour when the traversed set is changed during the traverse is not defined.

## 14 Expandable compact sparse set

The package ‘spsets’ can be used to represent few sets as the set memory is proportional to maximal possible element value. And as this value can be big, the sets can be big too. In some applications (e.g. basic block pseudo live info at the beginning and end of each basic block in compiler) you need a lot of sets and spset package is not acceptable for such uses as it will require huge memory. We need a set representation whose memory is proportional to number of set elements which for sparse sets is much smaller than maximal possible element value. The package ‘cspset’ (expandable compact sparse sets) implements such representation. We use special case hash tables of appropriate sizes to keep the tables compact but still fast for access. The

algorithm complexities of set operations in practice is the same as for package ‘spset’ but have bigger constants.

The interface part of the sparse set is file ‘cspset.h’. The implementation part is file ‘cspset.cpp’. The interface is very similar to ‘spset’ one. It contains the following external definitions and macros:

#### **Type ‘cspset\_elem\_t’**

is an unsigned integer type representing the set element. It is the same type as spset\_elem\_t.

#### **Constant ‘cspset\_max\_elem’**

is a maximal possible value of the previous type for the element. That is pretty big value very close to maximal value of the above type.

#### **Class ‘cspset’**

describes a compact sparse set. The class contains the following functions:

##### **Public constructor ‘cspset’**

```
‘cspset (cspset_elem_t size = 0)’
```

creates set with initial size close to ‘size’ but not less than it. With default parameter value the minimal size set is created.

##### **Public destructor ‘cspset’**

```
‘~cspset (void)’
```

deletes given set and frees memory allocated for it.

##### **Public member function ‘size’**

```
‘cspset_elem_t size (void)’
```

returns the current size of the set. The set without an expansion can contain elements whose quantity is close to the set size.

##### **Public member function ‘cardinality’**

```
‘cspset_elem_t cardinality (void)’
```

returns number of elements containing currently in the set.

##### **Public member function ‘copy’**

```
‘void copy (cspset *from)’
```

copies value of set ‘from’ to given set.

##### **Public member function ‘swap’**

```
‘void swap (cspset *s)’
```

swaps values of given set and ‘s’.

##### **Public member function ‘in\_p’**



```
'int in_p (cspset_elem_t el)'
```

returns TRUE if the set contains element 'el'.

**Public member function 'insert'**

```
'int insert (cspset_elem_t el)'
```

inserts element 'el' into the set. Return TRUE if the set has been changed, in other words, it did not contain the element. If the set size is not enough to contain the element, the set is expanded.

**Public member function 'remove'**

```
'int remove (cspset_elem_t el)'
```

removes element 'el' from the set. Return TRUE if the set has been changed, in other words, it really contained the element.

**Public member function 'clear'**

```
'int clear (void)'
```

removes all elements from the set. Return TRUE if the set has been changed, in other words, it was not empty.

**Public member function 'equal\_p'**

```
'int equal_p (cspset *s)'
```

returns TRUE if given set and 's' contain exactly the same elements.

**Public member function 'intersect'**

```
'int intersect (cspset *s)'
```

removes elements in given set which are not in set 's'. Returns TRUE if the set has been changed, in other words, if given set or 's' had any non-common elements.

**Public member function 'unity'**

```
'int unity (cspset *s)'
```

adds all elements of set 's' to given set. Returns TRUE if the set has been changed, in other words, if any new element was added to given set. The set can be automatically expanded if it is necessary.

**Public member function 'diff'**

```
'int intersect (cspset *s)'
```

removes all elements of set 's' from given set. Returns TRUE if the set has been changed, in other words, if given set and 's' had any common elements.

**Public member function 'shrink'**

```
'void shrink (void)'
```

decreases size of the set if it is possible. During set life, the set can be automatically expanded but it is never automatically shrunk. After some element removes, it might be possible to shrink set size to save memory. The function serves this purpose.

**Public static function ‘release\_unused\_memory’**

```
‘void release_unused_memory (void)’
```

releases internal memory pool. The pool is used to speed up size changing of sets. It is wise to call the function when you finish to work with all sets.

**Public member function ‘print’**

```
‘void print (FILE *f)’
```

prints all elements of the set into file ‘f’.

**Public member function ‘debug’**

```
‘void debug (void)’
```

prints all elements of the set into stderr.

**Function ‘to\_spset’**

```
‘void to_spset (spset_t *to)’
```

is used to transform given compact sparse set to sparse set ‘to’.

**Function ‘from\_spset’**

```
‘void from_spset (spset_t *from)’
```

is used to transform given compact sparse set from sparse set ‘from’.

**Class ‘cspset\_iterator’**

is used to define iterators for traverses of sets (see the macro below).

**Macro ‘EXECUTE\_FOR\_EACH\_CSPSET\_ELEM’**

```
‘EXECUTE_FOR_EACH_CSPSET_ELEM (SET, EL, SI) c++-stmt’
```

executes ‘c++-stmt’ for each element of ‘SET’. During execution, the current element value is assigned to ‘EL’. You need to declare somewhere and use iterator ‘SI’ in the macro call. The order of traverse of the set elements is undefined. The traverse behaviour when the traversed set is changed during the traverse is not defined.

## 15 Earley parser

The package ‘earley’ implements earley parser. The earley parser implementation has the following features:

- It is sufficiently fast and does not require much memory. This is the fastest implementation of Earley parser which I know. The main design goal is to achieve speed and memory requirements which are necessary to use it in prototype compilers and language processors. It parses 30K lines of C program per second on 500 MHz Pentium III and allocates about 5Mb memory for 10K line C program.
- It makes simple syntax directed translation. So an abstract tree is already the output of Earley parser.
- It can parse input described by an ambiguous grammar. In this case the parse result can be an abstract tree or all possible abstract trees. Moreover it produces the compact representation of all possible parse trees by using DAG instead of real trees. This feature can be used to parse natural language sentences.
- It can parse input described by an ambiguous grammar according to the abstract node costs. In this case the parse result can be a minimal cost abstract tree or all possible minimal cost abstract trees. This feature can be used to code selection task in compilers.
- It can make syntax error recovery. Moreover its error recovery algorithms find error recovery with minimal number of ignored tokens. It permits to implement parsers with very good error recovery and reporting.
- It has fast startup. There is no practically delay between processing grammar and start of parsing.
- It has flexible interface. The input grammar can be given by YACC-like description or providing functions returning terminals and rules.
- It has good debugging features. It can print huge amount of information about grammar, parsing, error recovery, translation. You can even output the result translation in form for a graphic visualization program.

The interface part of the parser is file ‘earley.h’. The implementation part is file ‘earley.cpp’. The interface contains the following external definitions and macros:

**Macro ‘EARLEY\_NIL\_TRANSLATION\_NUMBER’**

is reserved to be designation of empty node for translation.

**Macro ‘EARLEY\_NO\_MEMORY’**

is error code of the parser. The parser functions return the code when parser can not allocate enough memory for its work.

**Macro ‘EARLEY\_UNDEFINED\_OR\_BAD\_GRAMMAR’**

is error code of the parser. The parser functions return the code when we call parsing without defining grammar or call parsing for bad defined grammar.

**Macro ‘EARLEY\_DESCRIPTION\_SYNTAX\_ERROR\_CODE’**

is error code of the parser. The code is returned when the grammar is defined by description and there is syntax error in the description.

**Macro ‘EARLEY\_FIXED\_NAME\_USAGE’**

is error code of the parser. The code is returned when the grammar uses reserved names for terminals and nonterminals. There are two reserved names ‘\$S’ (for axiom) and ‘\$eof’ for end of file (input end marker). The parser adds these symbols and rules with these symbols to the grammar given by user. So user should not use these names in his grammar.

**Macro ‘EARLEY\_REPEATED\_TERM\_DECL’**

is error code of the parser. The code is returned when the grammar contains several declarations of terminals with the same name.

**Macro ‘EARLEY\_NEGATIVE\_TERM\_CODE’**

is error code of the parser. The code is returned when the grammar terminal is described with negative code.

**Macro ‘EARLEY\_REPEATED\_TERM\_CODE’**

is error code of the parser. The code is returned when the two or more grammar terminals are described with the same code.

**Macro ‘EARLEY\_NO\_RULES’**

is error code of the parser. The code is returned when the grammar given by user has no rules.

**Macro ‘EARLEY\_TERM\_IN\_RULE\_LHS’**

is error code of the parser. The code is returned when grammar rule given by user contains terminal in left hand side of the rule.

**Macro ‘EARLEY\_INCORRECT\_TRANSLATION’**

is error code of the parser. The code is returned when grammar rule translation is not correct. The single reason for this is translation of the rule consists of translations of more one symbols in the right hand side of the rule without forming an abstract tree node.

**Macro ‘EARLEY\_NEGATIVE\_COST’**

is error code of the parser. The code is returned when abstract node has a negative cost.

**Macro ‘EARLEY\_INCORRECT\_SYMBOL\_NUMBER’**

is error code of the parser. The code is returned when grammar rule translation contains incorrect symbol number which should be nonnegative number less than rule right hand side length.

**Macro ‘EARLEY\_UNACCESSIBLE\_NONTERM’**

is error code of the parser. The code is returned when there is grammar nonterminal which can not be derived from axiom.

**Macro ‘EARLEY\_NONTERM\_DERIVATION’**

is error code of the parser. The code is returned when there is grammar nonterminal which can not derive a terminal string.

**Macro ‘EARLEY\_LOOP\_NONTERM’**

is error code of the parser. The code is returned when there is grammar nonterminal which can derive only itself. The parser does not work with such grammars.

**Macro ‘EARLEY\_INVALID\_TOKEN\_CODE’**

is error code of the parser. The code is returned when the parser got input token whose code is different from all grammar terminal codes.

**Enumeration ‘earley\_tree\_node\_type’**

describes all possible nodes of abstract tree representing the translation. There are the following enumeration constants:

**‘EARLEY\_NIL’**

the corresponding node represents empty translations.

**‘EARLEY\_ERROR’**

the corresponding node represents translation of special terminal ‘error’ (see error recovery).

**‘EARLEY\_TERM’**

the corresponding node represents translation of a terminal.

**‘EARLEY\_ANODE’**

the corresponding node represents an abstract node.

**‘EARLEY\_ALT’**

the corresponding node represents an alternative of the translation. Such nodes creates only when there are two or more possible translations. It means that the grammar is ambiguous.

**Structure ‘earley\_tree\_node’**

represents node of the translation. The nodes refer for each other forming DAG (direct acyclic graph) in general case. The main reason of generating DAG is that some input fragments may have the same translation, when there are several parsings of input (which is possible only for ambiguous grammars). But DAG may be created even for unambiguous grammar because some nodes (empty and error nodes) exist only in one exemplar. When such nodes are not created, the translation nodes forms a tree. This structure has the following members:

**Member ‘type’ of type ‘enum earley\_tree\_node\_type’**

representing type of the translation node.

**Union ‘val’**

Depending on the translation node type, one of the union members ‘nil’, ‘error’, ‘term’, ‘anode’, and ‘alt’ of the structure types described below is used to represent the translation node.

**Structure ‘earley\_nil’**

represents empty node. It has no members. Actually the translation is DAG (not tree) in general case. The empty and error nodes are present only in one exemplar.

**Structure ‘earley\_error’**

represents translation of special terminal ‘error’. It has no members. The error node exists only in one exemplar.

**Structure ‘earley\_term’**

represents translation of terminals. It has the following two members:

**Integer member ‘code’**

representing code of the corresponding terminal.

**Member ‘cost’ of type ‘int’**

representing cost of the node plus costs of all children if the cost flag is set up. Otherwise, the value is cost of the abstract node itself.

**Member ‘attr’ of type ‘\* void’**

is reference for the attribute of the corresponding terminal.

**Structure ‘earley\_anode’**

represents abstract node. It has the following two members:

**Member ‘name’ of type ‘const char \*’**

representing name of anode as it given in the corresponding rule translation.

**Member ‘children’ of type ‘struct earley\_tree\_node \*\*’**

is array of nodes representing the translations of the symbols given in the rule with the abstract node.

**Structure ‘earley\_alt’**

represents an alternative of the translation. It has the following two members:

**Member ‘node’ of type ‘struct earley\_tree\_node \*’**

representing alternative translation.

**Member ‘next’ of type ‘struct earley\_tree\_node \*’**

is reference for the next alternative of translation.

**Class ‘earley’**

Earley parsers are objects of this class. The class has the following members:

**Public constructor ‘earley’**

```
‘earley (void)’
```

creates new parser. The grammar of the parser is not defined.

**Public destructor**

```
‘~earley (void)’
```

frees all memory allocated for the parser.

**Public function ‘error\_code’**

```
‘int error_code (void)’
```

returns the last occurred error code (see the possible error codes above) for given parser. If the function returns zero, no error was found so far.

**Public function ‘error\_message’**

```
‘const char *error_message (void)’
```

returns detail message about last occurred error. The message always corresponds to the last error code returned the previous function.

**Public function ‘read\_grammar’**

```

'int read_grammar (int strict_p,
                  const char *(*read_terminal) (int *code),
                  const char *(*read_rule)
                  (const char ***rhs,
                   const char **abs_node,
                   int *anode_cost,
                   int **transl))'

```

is one of two functions which tunes the parser to given grammar. The grammar is read with the aid functions given as parameters.

'read\_terminal' is function for reading terminals. This function is called before function 'read\_rule'. The function should return the name and the code of the next terminal. If all terminals have been read the function returns NULL. The terminal code should be nonnegative. 'read\_rule' is function called to read the next rule. This function is called after function 'read\_terminal'. The function should return the name of nonterminal in the left hand side of the rule and array of names of symbols in the right hand side of the rule (the array end marker should be 'NULL'). If all rules have been read, the function returns 'NULL'. All symbol with name which was not provided function 'read\_terminal' are considered to be nonterminals. The function also returns translation given by abstract node name and its fields which will be translation of symbols (with indexes given in array given by parameter 'transl') in the right hand side of the rule. All indexes in 'transl' should be different (so the translation of a symbol can not be represented twice). The end marker of the array should be a negative value. There is a reserved value of the translation symbol number denoting empty node. It is value defined by macro 'EARLEY\_NIL\_TRANSLATION\_NUMBER'. If parameter 'transl' is 'NULL' or contains only the end marker, translations of the rule will be empty node. If 'abs\_node' is 'NULL', abstract node is not created. In this case 'transl' should be null or contain at most one element. This means that the translation of the rule will be correspondingly empty node or the translation of the symbol in the right hand side given by the single array element. The cost of the abstract node if given is passed through parameter 'anode\_cost'. If 'abs\_node' is not 'NULL', the cost should be greater or equal to zero. Otherwise the cost is ignored.

There is reserved terminal 'error' which is used to mark start point of error recovery.

Nonzero parameter 'strict\_p' value means more strict checking the grammar. In this case, all nonterminals will be checked on ability to derive a terminal string instead of only checking axiom for this.

The function returns zero if it is all ok. Otherwise, the function returns the error code occurred.

#### Public function 'parse\_grammar'

```

'int parse_grammar (int strict_p, const char *description)'

```

is another function which tunes the parser to given grammar. The grammar is given by string 'description'. The description is similiar YACC one. It has the following syntax:

```

file : file terms [';']
      | file rule
      | terms [';']
      | rule

terms : terms IDENTIFIER ['=' NUMBER]

```

```

| TERM

rule : IDENTIFIER ':' rhs [';']

rhs : rhs '|' sequence [translation]
    | sequence [translation]

sequence :
    | sequence IDENTIFIER
    | sequence C_CHARACTER_CONSTANT

translation : '#'
            | '#' NUMBER
            | '#' '-'
            | '#' IDENTIFIER '(' numbers ')',

numbers :
    | numbers NUMBER
    | numbers '-'

```

So the description consists of terminal declaration and rules sections.

Terminal declaration section describes name of terminals and their codes. Terminal code is optional. If it is omitted, the terminal code will be the next free code starting with 256. You can declare terminal several times (the single condition its code should be the same).

Character constant present in the rules is a terminal described by default. Its code is always code of the character constant.

Rules syntax is the same as YACC rule syntax. The single difference is an optional translation construction starting with '#' right after each alternative. The translation part could be a single number which means that the translation of the alternative will be the translation of the symbol with given number (symbol numbers in alternative starts with 0). Or the translation can be empty or '-' which mean empty node. Or the translation can be abstract node with given name, optional cost, and with fields whose values are the translations of the alternative symbols with numbers given in parentheses after the abstract node name. You can use '-' in abstract node to show that empty node should be used in this place. If the cost is absent it is believed to be one. The cost of terminal, error node, and empty node is always zero.

There is reserved terminal 'error' which is used to mark start point of error recovery.

#### Public function 'set\_lookahead\_level'

```
'int set_lookahead_level (int level)'
```

sets up level of usage of look ahead in parser work. Value zero means no usage of lookaheads at all. Lookahead with static (independent on input tokens) context sets in parser situation (value 1) gives the best results with the point of view of space and speed, lookahead with dynamic (dependent on input tokens) context sets in parser situations (all the rest parameter values) does slightly worse, and no usage of lookaheads does the worst. The default value is 1 (lookahead with static situation context sets). The function returns the previously set up level. If the level value is negative, zero is used instead of it. If the value is greater than two, two is used in this case.

#### Public function 'set\_debug\_level'



```
'int set_debug_level (int level)'
```

sets up level of debugging information output to 'stderr'. The more level, the more information is output. The default value is 0 (no output). The debugging information includes statistics, result translation tree, grammar, parser sets, parser sets with all situations, situations with contexts. The function returns the previously set up debug level. Setting up negative debug level results in output of translation for program 'dot' of graphic visualization package 'graphviz'.

**Public function 'set\_one\_parse\_flag'**

```
'int set_one_parse_flag (int flag)'
```

sets up building only one translation tree (parameter value 0) or all parse trees for ambiguous grammar for which several parsings are possible. For unambiguous grammar the flag does not affect the result. The default value is 1. The function returns the previously used flag value.

**Public function 'earley\_set\_cost\_flag'**

```
'int set_cost_flag (int flag)'
```

sets up building only translation tree (trees if we set up one\_parse\_flag to 0) with minimal cost. For unambiguous grammar the flag does not affect the result. The default value is 0. The function returns the previously used flag value.

**Public function 'set\_error\_recovery\_flag'**

```
'int set_error_recovery_flag (int flag)'
```

sets up internal flag whose nonzero value means making error recovery if syntax error occurred. Otherwise, syntax error results in finishing parsing (although function 'syntax\_error' in function 'parse' will be called once). The default value is 1. The function returns the previously used flag value.

**Public function 'set\_recovery\_match'**

```
'int set_recovery_match (int n_toks)'
```

sets up recovery parameter which means how much subsequent tokens should be successfully shifted to finish error recovery. The default value is 3. The function returns the previously used flag value.

**Public function 'parse'**

```
'int parse (int (*read_token) (void **attr),
            void (*syntax_error)
              (int err_tok_num, void *err_tok_attr,
               int start_ignored_tok_num,
               void *start_ignored_tok_attr,
               int start_recovered_tok_num,
               void *start_recovered_tok_attr),
            void *(*parse_alloc) (int nmemb),
            void (*parse_free) (void *mem),
            struct earley_tree_node **root,
            int *ambiguous_p)'
```

is major parser function. It parses input according the grammar. The function returns the error code (which can be also returned by 'error\_code'). If the code is zero, the function will also return root of the parse tree through parameter 'root'. The tree representing the translation. Value passed through 'root' will be 'NULL' only if syntax error was occurred and error recovery was switched off. The function sets up flag passed by parameter 'ambiguous\_p' if we found that the grammar is ambiguous (it works even we asked only one parse tree without alternatives).

Function 'read\_token' provides input tokens. It returns code the next input token and its attribute. If the function returns negative value we've read all tokens.

Function 'syntax\_error' called when syntactic error has been found. It may print an error message about syntax error which occurred on token with number 'err\_tok\_num' and attribute 'err\_tok\_attr'. The following four parameters describes made error recovery which ignored tokens starting with token given by 3rd and 4th parameters. The first token which was not ignored is described by the last parameters. If the number of ignored tokens is zero, the all parameters describes the same token. If the error recovery is switched off (see comments for 'set\_error\_recovery\_flag'), the third and the fifth parameters will be negative and the forth and the sixth parameters will be 'NULL'.

Function 'parse\_alloc' is used by Earley parser to allocate memory for parse tree representation (translation). After calling the class destructor we free all memory allocated for the parser. At this point it is convenient to free all memory but parse tree. Therefore we require the following function. So the caller will be responsible to allocate and free memory for parse tree representation (translation). But the caller should not free the memory until destructor is called for the parser. The function may be called even during reading the grammar not only during the parsing. only during the parsing. Function 'parse\_free' is used by the parser to free memory allocated by 'parse\_alloc'. If it is 'NULL', the memory is not freed.