Programming assignment – Sparse Vector

Traditionally vectors are implemented using an array data structure (static or dynamic). In this assignment you will use linked-list data structure to obtain memory-efficient implementation of vectors. The assignment should give you an additional practice with pointers and dynamical memory allocation. The goal is to implement several functions that manipulate nodes in a linked list. This functions include the traditional list operations like inserting, removing, searching, as well as several vector-related functions – scalar product and addition.

Here is a structure to represent a linked list node

```
struct ElementNode {
  int    data;
  int    pos;
  struct ElementNode *next;
};
```

Integer `data` is the value which is stored in the node. Compared to the traditional node ours has an additional field – `pos`, which represents element's index in the vector. Since the nodes are to be used in a singly linked list, we have a pointer to the next element `next`.

Opaque pointers

First of all, if you were using regular C-style pointers, you'd put the above definition of `ElementNode` in the beginning of `spvector.h` and your functions would look like:

`int scalar_product(ElementNode const *p_e1, ElementNode const *p_e2);`

For this assignment you are required to use opaque pointers – here is a roadmap to convert existing code that uses pointers do opaque pointers. I'll also explain why regular pointer are bad.

1. move struct `ElementNode` definition into `spvector.c` (thus it is hidden from the client)

2. in `spvector.h` add
   `typedef struct ElementNode* ElementNode_handle;`
   `typedef const struct ElementNode* ConstElementNode_handle;` (see source code for explanation)
   note that when compiler reads the above line, it DOES NOT know the definition of `ElementNode` – `spvector.c` has not been seen yet (make sure you understand why). Therefore `ElementNode` is an incomplete type. The rule in C/C++ is that pointers to incomplete types are legal (but dereferencing of those pointers is not)

3. rewrite all function to use `ElementNode_handle` instead of `ElementNode*` and `ElementNode_handle*` instead of `ElementNode**`. Note that inside `spvector.c` you may use `ElementNode` type and `ElementNode` structure fields, since by that time compiler will have full information about `ElementNode` structure. Note that inside `spvector.h` you may NOT use `ElementNode*` and `ElementNode_handle` interchangeably.

   Example: this is legal in `spvector.c`, but not `spvector.h` and `driver.c`:

   ```
   ElementNode p = ...;
   p.pos = 5;
   ```

So what?

As we mentioned, since `->next` is illegal in the driver, client cannot modify keys and linked list is safe. To make modification of `next` value possible, implement `setNext(...)` function. Notice how much similar opaque pointers to private data in a C++ class!

Opaque pointers are more than just safety. They also provide encapsulation. Here is a typical example: in a big project we have a struct `ElementNode` in a file `spvector.h` – so it's definition is visible to everyone. `ElementNode` uses `next` and `pos` names for its fields. Since `next` and `pos` names are visible to the client (like public data in a C++ class) other files may use them (and will do that, even though methods like `getnext()` and `getpos()` are implemented). Then the maintainer of `spvector.h` decides to change the names to `Next` and `Pos` (or may be change their types or eliminate them completely). Now every file that uses `spvector.h` is broken and has to be updated, which may be a lot of work. Opaque pointers help to avoid this kind of problems by **forcing** the clients to use available getters and setters `getnext()` and `getpos()` instead of directly accessing the data. So now the change will proceed like this:

- implementor changes `next` to `Next`
- updates getnext() from
  ... getnext() return next;
  to
  ... getnext() return Next;

- recompiles the project

that's all, no other code is effected since everyone was using `getnext()` instead of `next`.

back to sparse vectors

These nodes may be used to represent a very long vector of integers most of which are 0's. Example vector $(0, 0, 0, 1, 0, 0, 0, 0, 0, 0, 0, 2)$ is a vector with 1 at position 3 and 2 at position 11 (counting from 0). When stored in an array, the array size should be at least 12 (which gives $12 * 4 = 48$ bytes). When stored as a list, the vector looks like `(1,3)->(2,11)`, where the first number in the pair is the value and second is position. So that the total amount of memory used is 2 nodes, which is $2 * (4 + 4 + 4) = 24$ bytes only.

The idea is to save storage space by never storing 0's. Make sure that all functions that modify the vector test for 0 before actually writing into it. Note that insert function may be used to overwrite a value, that is `insert_element(list,pos,val)`

- creates a new node if no node at position `pos` exists
- just modifies the data if a node at position `pos` exists
- deletes a node at position `pos` exists if `val=0`

This type of vector is usually known as *sparse vector*.

List representation has only one drawback – it doesn't remember the length of the original vector, e.g. both $(0, 0, 0, 1, 2, 0, 0, 0)$ and $(0, 0, 0, 1, 2, 0, 0, 0, 0, 0, 0, 0, 0, 0)$ have the same list representation `(1,3)->(2,4)`. Functions that require size information will have an additional parameter – dimension of the vector, see `printf_elements`.

Functions to be implemented are insert (ordered by position), delete at position.

Because lists with positions may be viewed as vectors, there are additional functions that may be useful:

- `get` the value at the given position – similar to index operator.
- vector addition
- scalar multiplication

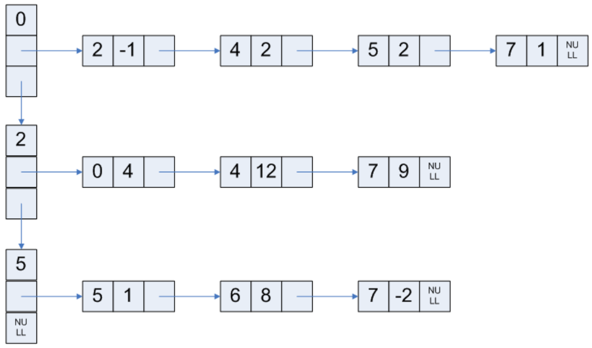
Extra credit part 30 points Almost every library that implements a matrix-like type does it by reusing a vector type. We can do the same by introducing an additional type `RowNode`:

```
struct RowNode {
  int pos;
  struct ElementNode *elements;
  struct RowNode *next;
};
```

This type is basically yet another node for a singly linked list of rows (vectors) which allows several lists of the `ElementNode` type to be tied together. For example, if we have a matrix with only 3 non-zero rows:

```
0'th row (0, 0,-1, 0,  2, 2, 0, 1)
2'nd row (4, 0, 0, 0, 12, 0, 0, 9)
5'th row (0, 0, 0, 0, 0,  1, 8,-2)
```

graphical representation for the above structure is



and as a matrix (I used `printf_rows(p_r, "%4i",8);`)

```
(0, 0,-1, 0,  2, 2, 0, 1)
(0, 0, 0, 0,  0, 0, 0, 0)
(4, 0, 0, 0, 12, 0, 0, 9)
(0, 0, 0, 0,  0, 0, 0, 0)
(0, 0, 0, 0,  0, 0, 0, 0)
(0, 0, 0, 0,  0, 1, 8,-2)
(0, 0, 0, 0,  0, 0, 0, 0)
(0, 0, 0, 0,  0, 0, 0, 0)
```

where rows 1,3,4,6,7 are all-zero rows. Row 6,7 are added to make the structure look like 8x8 matrix (see the second parameter of `printf_rows`.

Extra credit (20 pts): implement `determinant` function – see bottom of `spvector.h`. If you choose not to implement it – provide an empty implementation like:

```
int  determinant(const RowNode *p_r,int dim) {
  /* print args to get rid of warnings */
  printf("%p\n",(void*)p_r);
  printf("%i\n",dim);
  return 0;
}
```

Notes: The header file contains functions that need to be implemented. Several function will call other function you've implemented, so the total amount of work is not that big.

Criteria:

- For this assignment, you are not allowed to use any **for** loops. All of the list traversals must use **while** or **do...while** loops with pointer tests like `pList==NULL`. Do not use non-pointer tests – this is the same as having a **for** loop. Note that I had to use **for** loops in `printf...` functions. If you feel that you need a **for** loop for the extra credit part – talk to me first.

- Simpler implementation of `determinant` function uses recursion.

- Compilation (see Makefile in the project folder), you may use it as `make gcc0`, `make bcc0`, `make msc0` from bash and MS command prompt if the latter has Cygwin in the PATH variable).

- you should also test with Borland CodeGuard, compile with `make bcc_cg` and run the tests normally (you DO NOT add 100 to the test number). After each test check the content of the file `bcc_cg.cgl`. If it's empty, everything is OK. Otherwise there are problems, content of the log-file (cgl = code-guard log) should help you to track it down. See "memory errors" on the class web-site for some common mistakes. Check out `bcc_cg.cgi` – CodeGuard initialization/configuration for this project (you may modify it if you know what you are doing, I'll use the provided configuration for grading),

```
[Options]
CodeGuard=yes
Stats=no                #display run-time statistics
MessageBox=yes          #pop-up window in the case of an error
DebugInfo=yes           #very useful
```

```
Append=no               #append or overwrite log file
Repeats=yes             #???
Srcpath=                #I think it defaults to "current folder", so OK
IgnoredModules=         #we may add STL here
ErrorCaption=Error
ErrorText=There are errors in the program. A log file will be created.
OutputDebugString=no
StackFillFrequency=2
ResourceLeakReport=yes
MaxCGLerrors=65535
LimitCGLerrors=no
```

To submit

You must submit electronically through submission page a single zip-file containing:

- implementation file `spvector.c`
- header file `spvector.h`, you should only modify the comments – make them doxygen-style. Do not modify function signatures – otherwise my driver may not compile.