Programming Abstraction in C++

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2010
Chapter 10. Efficiency and Data Representation
Outline

1. An Editor Buffer
2. Implementation I: Character Array
3. Implementation II: Stacks
4. Implementation III: Linked List
Introduction

Goal
Use editor buffer as an example to illustrate how the choice of data representation affects the efficiency of applications.

Method
Use a low-level built-in structure, such as character array, so the operations are visible and thus easier to assess efficiency.

Lesson
Find options and evaluate the trade-offs. A good design demands compromise.

Important
The external behavior of an editor buffer (Table 10-1, p. 340) must remain the same while implementation changes.
Operations

- Move the cursor forward one position
  moveCursorForward()
- Move the cursor backward one position
  moveCursorBackward()
- Jump the cursor to the beginning (before the first character)
  moveCursorToStart()
- Move the cursor to the end (after the last character)
  moveCursorToEnd()
- Insert a character at the current cursor position
  insertCharacter(char ch)
- Delete the character just after the cursor position
  deleteCharacter()
- Display the content of the buffer
  display()
Interface design

Constructor

EditorBuffer()

Destructor

~EditorBuffer()
Interface design

Constructor

EditorBuffer()

Destructor

~EditorBuffer()

Commands:
F: move forward
B: move backward
J: jump to beginning
E: jump to end
Ixxx: insert characters xxx
D: delete
Q: quit editor
Interface design (cont.)

The interface, the public section, Figure 10-1, p. 343-344.

Study

- Documentation
- Style (boilerplate, class definition)
- The public method prototypes
- The private section is included from a file bufpriv.h
Interface design (cont.)

The interface, the public section, Figure 10-1, p. 343-344.

Study

- Documentation
- Style (boilerplate, class definition)
- The public method prototypes
- The private section is included from a file `bufpriv.h`

Now that you have the interface, you can write an application program solely based on it, without knowing the implementation. The application program should not be affected when implementation changes.
Command-driven editor

Figure 10-2, p. 346

Pattern: command-driven editor

```cpp
int main() {
    EditorBuffer buffer;
    while (true) {
        cout << "*";
        string cmd = GetLine();
        if (cmd != "") ExecuteCommand(buffer, cmd);
        buffer.display();
    }
    return 0;
}
```
A shell program is similar.
void ExecuteCommand(EditorBuffer & buffer, string line) {
    switch (toupper(line[0])) {
    case 'I':
        for (int i = 1; i < line.length(); i++) {
            buffer.insertCharacter(line[i]);
        }
        break;
    case 'D':
        buffer.deleteCharacter(); break;
    case 'F':
        buffer.moveCursorForward(); break;
    case 'B':
        buffer.moveCursorBackward(); break;
    case 'J':
        buffer.moveCursorToStart(); break;
    case 'E':
        buffer.moveCursorToEnd(); break;
    case 'Q':
        exit(0);
    default:
        cout << "Illegal command" << endl; break;
    }
}
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Private data representation

**Buffer**  A character array of fixed capacity, which can be extended like the dynamic `CharStack`. Current length of the buffer.

**cursor**  Position, the index of the character that immediately follows the cursor.
Private data representation

**Buffer**  A character array of fixed capacity, which can be extended like the dynamic `CharStack`. Current length of the buffer.

**cursor**  Position, the index of the character that immediately follows the cursor.

Private instance variables:

```c
char *array;
int capacity;
int length;
int cursor;
```
Implementing the methods

Moving cursor operations are straightforward.

Constructor and destructor, Figure 10-3, p. 349

```cpp
EditorBuffer::EditorBuffer() {
    capacity = INITIAL_CAPACITY;
    array = new char[capacity];
    length = 0;
    cursor = 0;
}

EditorBuffer::~EditorBuffer() {
    delete[] array;
}
```
moveCursorToEnd

```cpp
void EditorBuffer::moveCursorToEnd() {
    cursor = length;
}
```

The size of the array must be at least `length + 1`.
buffer.insertCharacter(‘X’);

Before
buffer.insertCharacter('X');

After

array
capacity
length
cursor

H E L X L O
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
Figure 10-3, p. 350

void EditorBuffer::insertCharacter(char ch) {
    if ((length + 1) == capacity) expandCapacity();
    for (int i = length; i > cursor; i--) {
        array[i] = array[i - 1];
    }
    array[cursor] = ch;
    length++;
    cursor++;
}

expandCapacity (p. 351) is similar to CharStack counterpart (p.326).
Figure 10-3, p. 350

```cpp
void EditorBuffer::insertCharacter(char ch) {
    if ((length + 1) == capacity) expandCapacity();
    for (int i = length; i > cursor; i--) {
        array[i] = array[i - 1];
    }
    array[cursor] = ch;
    length++;
    cursor++;
}
```

`expandCapacity (p. 351) is similar to CharStack counterpart (p.326).`

`deleteCharacter (p. 350) is similar.`
Assessing complexity

Problem size $N$: buffer length

Operation count:

The operations (comparison, addition, assignment) in moving the cursor are independent of $N$ (constant). No loops.
Assessing complexity

The operations of copying characters (assignment) in insertion and deletion are dependent of the buffer length. A loop. In the worst cases, inserting a character in the beginning or deleting a character in the beginning requires copying the entire buffer.

```cpp
void EditorBuffer::insertCharacter(char ch) {
    if ((length + 1) == capacity) expandCapacity();
    for (int i = length; i > cursor; i--) {
        array[i] = array[i - 1];
    }
    array[cursor] = ch;
    length++;
    cursor++;
}
```
Assessing complexity (cont.)

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<tr>
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<tbody>
<tr>
<td>moveCursorForward</td>
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</tr>
<tr>
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</tr>
<tr>
<td>deleteCharacter</td>
<td>$O(N)$</td>
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Note. When we do a lot of insertions and deletions and the buffer is large, it gets slow.
Using stacks

Idea:
Breaking the buffer at the cursor boundary.
Two stacks: One contains the characters that precede the cursor; One contains the characters after the cursor.
Using stacks

Idea:
Breaking the buffer at the cursor boundary.
Two stacks: One contains the characters that precede the cursor; One contains the characters after the cursor.

Private data representation
CharStack before;
CharStack after;
Implementing the methods

Figure 10-4, pp. 355-356

```cpp
void EditorBuffer::moveCursorForward() {
    if (!after.isEmpty()) {
        before.push(after.pop());
    }
}
```

`moveCursorBackward` is similar. No loops.
Implementing the methods

Figure 10-4, pp. 355-356

```c++
void EditorBuffer::deleteCharacter() {
    if (!after.isEmpty()) {
        after.pop();
    }
}
```

insertCharacter is similar. No loops.
moveCursorToStart requires a loop.

```cpp
void EditorBuffer::moveCursorToStart() {
    while (!before.isEmpty()) {
        after.push(before.pop());
    }
}
```

Worst case: When the cursor is currently at the end, we have to move (assignment) the entire buffer.
moveCursorToStart requires a loop.

```
void EditorBuffer::moveCursorToStart() {
    while (!before.isEmpty()) {
        after.push(before.pop());
    }
}
```

Worst case: When the cursor is currently at the end, we have to move (assignment) the entire buffer.

moveCursorToEnd is similar. A loop.
## Assessing complexity

Table 10-3, p. 354.

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Outline

1. An Editor Buffer
2. Implementation I: Character Array
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4. Implementation III: Linked List
What is a linked list? Linked by what?
What is a linked list? Linked by what?
A list of cells linked by pointers.
Cell structure

The structure of a cell:

```c
struct cellT {  
    char ch;
    cellT *link;
}
```

A recursive type.
Private data

```c
struct cellT {
    char ch;
    cellT *link;
};
cellT *start;
cellT *cursor;
```

Use the special pointer value `NULL` to signify the end of a list.
Use a dummy cell at the beginning of a list. (Why?)
EditorBuffer::EditorBuffer() {
    // initialize dummy cell
    start = new cellT;
    start->link = NULL;
    // initialize cursor
    cursor = start;
}

A dummy cell.
Example

The cursor pointer points to the cell containing the character that immediately *precedes* the cursor.
Simple things first

void EditorBuffer::moveCursorForward() {
    if (cursor->link != NULL) {
        cursor = cursor->link;
    }
}

void EditorBuffer::moveCursorToStart() {
    cursor = start;
}
Move the cursor backward

Search from the start for the pointer pointing to the cell whose link field equals cursor.

```cpp
EditorBuffer::moveCursorBackward() {
    cellT *cp = start;
    if (cursor != start) {
        while (cp->link != cursor) {
            cp = cp->link;
        }
        cursor = cp;
    }
}
```

Requires a loop.
Move the cursor backward (cont.)

EditorBuffer::moveCursorBackward() {
    cellT *cp = start;
    if (cursor != start) {
        while (cp->link != cursor) {
            cp = cp->link;
        }
        cursor = cp;
    }
}
EditorBuffer::moveCursorBackward() {
    cellT *cp = start;
    if (cursor != start) {
        while (cp->link != cursor) {
            cp = cp->link;
        }
        cursor = cp;
    }
}
Move the cursor to the end

moveCursorToEnd is similar to moveCursorBackward.

```cpp
void EditorBuffer::moveCursorToEnd() {
    while (cursor->link != NULL) {
        moveCursorForward();
    }
}
```
Two patterns

Two linked list patterns

for (cp = start; cp->link != cursor; cp = cp->link) {
    ... code using cp ...
}

for (cellT *cp = start; cp != NULL; cp = cp->link) {
    ... code using cp ...
}

Example. display, p. 370.
void EditorBuffer::deleteCharacter() {
    if (cursor->link != NULL) {
        cellT *oldcell = cursor->link;
        cursor->link = oldcell->link;
        delete oldcell;
    }
}
Deletion (cont.)

```cpp
void EditorBuffer::deleteCharacter() {
  if (cursor->link != NULL) {
    cellT *oldcell = cursor->link;
    cursor->link = oldcell->link;
    delete oldcell;
  }
}
```
void EditorBuffer::deleteCharacter() {
    if (cursor->link != NULL) {
        cellT *oldcell = cursor->link;
        cursor->link = oldcell->link;
        delete oldcell;
    }
}
void EditorBuffer::insertCharacter(char ch) {
    cellT *cp = new cellT;
    cp->ch = ch;
    cp->link = cursor->link;
    cursor->link = cp;
    cursor = cp;
}
void EditorBuffer::insertCharacter(char ch) {
    cellT *cp = new cellT;
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void EditorBuffer::insertCharacter(char ch) {
    cellT *cp = new cellT;
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    cp->link = cursor->link;
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}
void EditorBuffer::insertCharacter(char ch) {
    cellT *cp = new cellT;
    cp->ch = ch;
    cp->link = cursor->link;
    cursor->link = cp;
    cursor = cp;
}
Destructor

EditorBuffer::~EditorBuffer() {
    cellT *cp = start;
    while (cp != NULL) {
        cellT *next = cp->link;
        delete cp;
        cp = next;
    }
}

Note.

- `cp` points to the cell to be deleted.
- Save the `link` field of the current cell in `next` before deleting the cell.
Relative efficiency

Table 10-4, p. 367.

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Question

If the cursor pointer pointed to the cell containing the character immediately after the cursor, how would it affect the efficiency?
Doubly linked list

To alleviate the problem of going backwards or to the end in linked list, we can use a circular doubly linked list with a dummy cell.

```c
struct cellT {
    char ch;
    cellT *prev;
    cellT *next;
}
```
Time-space trade-offs

In the doubly linked list implementation, all the operations have $O(1)$ complexity, however, it takes at least nine bytes for each character, about ten times the space in the array implementation.
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A hybrid method: A doubly linked list of arrays, where each array represents a line.
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A hybrid method: A doubly linked list of arrays, where each array represents a line.

A good design demands compromise.