Stack Applications

1. Evaluating Postfix Expressions
   - parsing a postfix expression
   - evaluating postfix expressions

2. Converting Infix to Postfix Expressions
   - converting infix sums
   - from infix to postfix

3. Extended Infix to Postfix
   - infix expressions with brackets
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A postfix expression is an arithmetic expression where we \textit{first} write the two operands \textit{and then} the operator.

Some examples with corresponding infix notation:

<table>
<thead>
<tr>
<th>postfix</th>
<th>infix</th>
</tr>
</thead>
<tbody>
<tr>
<td>9 8 *</td>
<td>9 * 8</td>
</tr>
<tr>
<td>3 4 5 + *</td>
<td>(4 + 5) * 3</td>
</tr>
<tr>
<td>3 4 + 5 *</td>
<td>(3 + 4) * 5</td>
</tr>
</tbody>
</table>

Advantage of postfix notation: no brackets needed.
reading from strings

Including \texttt{<sstream>} we can read from strings:

\begin{verbatim}
string expression;
getline(cin,expression,'\n');

istringstream tokens(expression);
char next_character;

while(tokens >> next_character)
    cout << next_character;
\end{verbatim}

Observe:

- \texttt{while(tokens >> next_character)} \textbf{means}: as long as extraction of a character succeeds,
- \texttt{tokens >> next_character} \textbf{reads next nonblank character}, so we naturally skip spaces.
const string operators = "+-*/";
istringstream arguments(expression);
bool valid = true;
while (arguments >> next_character) {
    if (!isdigit(next_character)) {
        if (operators.find(next_character) == string::npos) {
            cout << next_character << " is invalid operator" << endl;
            valid = false; break;
        } else
            cout << "operator : " << next_character << endl;
    } else
        cout << "operator : " << next_character << endl;
}
getting operands

else
{
    arguments.putback(next_character);
    int value;
    arguments >> value;
    cout << "operand : " << value << endl;
}

Observe:

- the `putback()` method unreads a character,
- with `arguments >> value` we read any integer.
Running parsing expression

Reading from a string twice:

$ /tmp/parsing
Give a postfix expression : 13 44 5 + *
-> your expression : "13 44 5 + *"
-> your expression : "13445+*"
-> parsing expression ...
operand : 13
operand : 44
operand : 5
operator : +
operator : *
$

Note: represent $-5$ as $0 5 -$.
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Evaluating a Postfix Expression

Given a postfix arithmetical expression, compute its value.

Using a stack, the algorithm evaluates expression as:

for every item in expression do
    if (item is operand) then
        push item on the stack
    else
        right = pop from stack
        left = pop from stack
        push (left item right) on the stack
result = pop from stack

Our pop is stack<int>.top() followed by stack<int>.pop()
Tracing the Evaluation

$ /tmp/test_eval
Give a postfix expression : 3 4 5 + *

-> your expression : "3 4 5 + *"

pushing 3
pushing 4
pushing 5
evaluating +
popping 5
popping 4
pushing 9
evaluating *
popping 9
popping 3
pushing 27
the value of "3 4 5 + *" : 27
$
an Object-Oriented Implementation

```
#include "Postfix_Evaluator.h"
#include <iostream>
#include <string>
using namespace std;

int main()
{
    string expression;
    
    cout << "Give a postfix expression : ";
    getline(cin,expression,'
');

    Postfix_Evaluator p(expression);

    cout << "the value of "
           << expression << "" : "
           << p.value() << endl;
```
data members of class

```cpp
#ifndef POSTFIX_EVALUATOR_H
#define POSTFIX_EVALUATOR_H
#include <stack>
#include <string>

class Postfix_Evaluator
{
    private:
        std::string expression;
        static const std::string operators;
        std::stack<int> operands;
}
```

We store given expression, the definition of the operators, and the stack of operands.
functions in class

private:
    bool is_operator(char c);
    // returns true if c is an operator

    int eval_operator(char c);
    // returns the value of one operator

public:
    Postfix_Evaluator(std::string s);
    // stores the expression

    int value();
    // returns the value of the expression

The functions declared under private are auxiliary to the public value method.
```
const std::string Postfix_Evaluator::operators = "+-*/";

bool Postfix_Evaluator::is_operator(char c) {
    return (operators.find(c) != std::string::npos);
}

int Postfix_Evaluator::eval_operator(char c) {
    int right = this->operands.top();
    this->operands.pop();
    int left = this->operands.top();
    this->operands.pop();
    switch(c) {
    case '+': return left + right;
    case '-': return left - right;
    case '*': return left * right;
    case '/': return left / right;
    }
}
```
int Postfix_Evaluator::value()
{
    std::istringstream tokens(this->expression);
    char c;
    while(tokens >> c)
    {
        if(is_operator(c))
        {
            int v = eval_operator(c);
            this->operands.push(v);
        }
        else
        {
            tokens.putback(c);
            int operand;
            tokens >> operand;
            this->operands.push(operand);
        }
    }
    return operands.top();
}
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from infix to postfix

Given a sum of integers, operators + and −, convert:

$ /tmp/converting
Give an infix sum : 234 − 88 + 921 − 8
-> your expression : "234 − 88 + 921 − 8"
postfix notation of "234 − 88 + 921 − 8" \nis "234 88 − 921 + 8 −"
$

Algorithm stores the previous operator.
For every item in the infix expression:

- if item is operand, write to result;
- if item is operator, write the previous operator and store item as the previous operator.

At end, write the previous operator to result.
writing to string

```cpp
#include <iostream>
#include <sstream>
#include <string>
using namespace std;

int main()
{
    string expression;

    cout << "Give an infix sum : ";
    getline(cin, expression, '\n');

    istringstream arguments(expression);
    char next_character;
    char previous_op = ' ';
    ostringstream postfix_expression;
```
converting expression

```c
while (arguments >> next_character)
{
    if (!isdigit(next_character))  // assume + or -
    {
        if (previous_op != ' ')
            postfix_expression << previous_op << " ";
        previous_op = next_character;
    }
    else
    {
        arguments.putback(next_character);
        int value;
        arguments >> value;
        postfix_expression << value << " ";
    }
}
postfix_expression << previous_op;
```
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Converting Infix to Postfix

Consider infix expressions with operators +, −, *, and /, without brackets.

Comparing "2 + 3/4" with "2/3 + 4", or equivalently "2 3 4 / +" with "2 3 / 4 +"
we see that precedence order of operators matters.

We maintain a stack of operators.
Comparing the current operator with the top of the stack,
we pop operators as long as their precedence is higher or
equal than the precedence of the current operator.
running the conversion

```
$ /tmp/test_convert
Give an infix expression : 2 + 3/4
pushing +
pushing /
popping /
popping +
the postfix notation of "2 + 3/4" : 2 3 4 / +
$ /tmp/test_convert
Give an infix expression : 2/3 + 4
pushing /
popping /
pushing +
popping +
the postfix notation of "2/3 + 4" : 2 3 / 4 +
```
The Conversion Algorithm

Given expression in infix notation.

for every item in expression do
    if (item is operator)
        then process the operator;
    else write item to result;
pop all operators from stack and write.

To process the current operator:

if (the stack is empty) then
    push current operator on the stack;
else if (current operator > operator on top) then
    push current operator on the stack;
else do
    pop operator on top and write;
    break if (stack is empty);
    while (current operator ≤ operator on top);
    push current operator on the stack.
```cpp
#include "Infix_to_Postfix.h"
#include <iostream>
#include <string>
using namespace std;

int main()
{
    string expression;

    cout << "Give an infix expression : ";
    getline(cin,expression,'
');

    Infix_to_Postfix e(expression);

    cout << "the postfix notation of "
         << expression << "\" : "
         << e.convert() << endl;
```
data members

```cpp
#ifndef INFIX_TO_POSTFIX_H
#define INFIX_TO_POSTFIX_H
#include <stack>
#include <sstream>
#include <string>

class Infix_to_Postfix {
    private:
        std::string expression;
        static const std::string operators;
        std::stack<char> operator_stack;
        std::ostringstream postfix_expression;

To share the result `postfix_expression` between various methods, we make it a data attribute.
```
private:
    bool is_operator(char c);
    // returns true if c is an operator
    int precedence_operator(char c);
    // returns precedence of operator c
    void process_operator(char c);
    // processes one operator

public:
    Infix_to_Postfix(std::string s);
    // stores the expression
    std::string convert();
    // returns the equivalent postfix expression
const std::string Infix_to_Postfix::operators = "+-*/";

bool Infix_to_Postfix::is_operator(char c)
{
    return (operators.find(c) != std::string::npos);
}

int Infix_to_Postfix::precedence_operator(char c)
{
    if(c == '+' || c == '-')
        return 1;
    else
        return 2;
}
the `convert()` method

```cpp
std::string Infix_to_Postfix::convert() {
    std::istringstream tokens(this->expression);
    char c;
    while(tokens >> c)
        if(is_operator(c))
            process_operator(c);
        else {
            tokens.putback(c);
            int operand;
            tokens >> operand;
            this->postfix_expression << operand << " ";
        }
    while(!this->operator_stack.empty()) {
        char c = this->operator_stack.top();
        this->postfix_expression << c << " ";
        this->operator_stack.pop();
    }
    return this->postfix_expression.str();
}
```
process_operator

```cpp
void Infix_to_Postfix::process_operator(char c) {
    if(this->operator_stack.empty())
        this->operator_stack.push(c);
    else {
        char top_op = this->operator_stack.top();
        if(precedence_operator(c) > precedence_operator(top_op))
            this->operator_stack.push(c);
        else {
            do {
                this->postfix_expression << top_op << " ";
                this->operator_stack.pop();
                if(this->operator_stack.empty()) break;
                top_op = this->operator_stack.top();
            } while(precedence_operator(c) <= precedence_operator(top_op));
            this->operator_stack.push(c);
        }
    }
}
```
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Infix with Brackets to Postfix

To convert \(3 \times (4 + 5)\) to \(3 4 5 + \times\) we view brackets (and) as operators.

To process a bracket operator:

- an opening bracket (is pushed on the stack
- at a closing bracket ), we pop all operators up to and including the matching opening bracket.

Modifications to Infix_to_Postfix:

1. Add ( and ) to static const string operators.
2. Define precedence of the brackets as zero.
3. Extend process_operator to test for ) and (.
Summary + Exercises

Expression manipulations use stack, we covered §5.4.

Exercises:

1. Define exception `Stack_Empty` to be thrown when postfix evaluator does top or pop on empty stack. Modify the class `Postfix_Evaluator` and test it on invalid postfix expressions.

2. Adjust one of our own stack applications of L-14 with a `to_string()` method that sends the content of the stack to a string. Use this `to_string()` to print the evolution of the stack in `Postfix_Evaluator`.

3. Extend the `Infix_to_Postfix` methods so they throw exceptions when the stack turns out empty when an invalid infix expression is given. Provide a handler (try - catch block) in the test program.