Hogebomen

Lisette de Schipper (s1396250) en Micky Faas (s1407937)

Abstract

Blabla

1 Inleiding

AVL-bomen, splay-bomen en treaps zijn klassieke datastructuren die ingezet worden om een verzameling gegevens te faciliteren. Het zijn zelfbalancerende binaire zoekbomen die elk een vorm van ruimte en/of tijd-efficiëntie aanbieden. Er worden experimenten verricht om de prestatie van deze zelf-balancerende zoekbomen te vergelijken, aan de hand van ophaaltijd van data, mate van herstructurering en het verwijderen van knopen. Ook wordt de prestatie van deze zoekbomen uitgezet tegen de ongebalanceerde tegenhanger, de binaire zoekboom.

2 Werkwijze

De vier bomen zijn conceptueel eenvoudig en relatief makkelijk te implementeren.

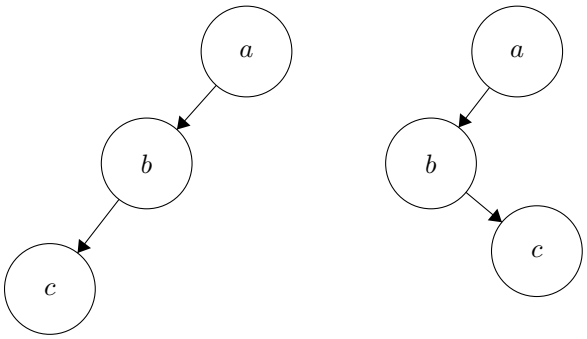
2.1 Implementatie binaire zoekboom

TO DO

2.2 Implementatie AVL-bomen

Knopen van een AVL-boom hebben een *balansfactor*, die altijd -1, 0 of 1 moet zijn. In deze implementatie is de balansfactor de hoogte van de rechtersubboom min de hoogte van de linkersubboom. Dit houdt dus in dat de hoogte van de linkersubboom van de wortel met maar 1 knoop kan verschillen van de hoogte van de rechtersubboom van de wortel. Het moment dat de balansfactor van een knoop minder dan -1 of meer dan 1 wordt, moet de boom geherstructureerd worden, om deze eigenschap te herstellen.

Om de balansfactor voor elke knoop te berekenen, houdt elke knoop zijn eigen hoogte bij. De balansfactor van een knoop wordt hersteld door rotaties. De richting en de hoeveelheid van de rotaties hangt af van de vorm van de betreffende (sub)boom. De volgende twee vormen en hun spiegelbeelden kunnen voorkomen bij het verwijderen of toevoegen van een knoop:



In het eerste geval moet de wortel naar rechts worden geroteerd. In het tweede geval moeten we eerst naar de staat van de eerste subboom komen, door b naar links te roteren. Voor de spiegelbeelden van deze twee vormen geldt hetzelfde alleen in spiegelbeeld.

In deze implementatie van een AVL-boom bedraagt het toevoegen van een knoop in het ergste geval O($logn$) tijd, waarbij n staat voor de hoogte van de boom. Eerst moet er gekeken worden of de data niet al in de boom voorkomt (O($logn$)) en vervolgens moet de boom op basis van de toevoeging geherstructureerd worden. Dit laatste is in het ergste geval O($logn$), omdat dan de gehele boom tot de wortel moeten worden nagelopen.
De complexiteitsgraad van het verwijderen van een knoop is gelijk aan die van het toevoegen van een knoop, omdat dezelfde operaties uitgevoerd moeten worden.

2.3 Implementatie Splay-bomen

TO DO

2.4 Implementatie Treaps

3 Onderzoek

4 Resultaten

5 Conclusies

6 Appendix

6.1 ExpressionAtom.h

```
1 /**
2  * ExpressionAtom:
3  *
4  * @author  Micky Faas (s1407937)
5  * @author  Lisette de Schipper (s1396250)
6  * @file    ExpressionAtom.h
7  * @date    26-10-2014
```

```
 **/

#ifndef EXPRESSIONATOM_H
#define EXPRESSIONATOM_H

#include <ostream>
#include <string>
#include <cmath>

typedef struct {
    int numerator;
    int denominator;
} Fraction;

/**
* @function  operator==( )
* @abstract  Test equality for two Fractions
* @param     lhs and rhs are two sides of the comparison
* @return    true upon equality
* @post      Two Fraction are equal if
*            lhs.numerator/lhs.denominator == rhs.numerator/rhs.denominator
**/
bool operator ==( const Fraction& lhs, const Fraction& rhs );

/**
* @function  Arithmetic operators +, -, *, /
* @abstract  Arithmetic result of two Fractions
* @param     lhs and rhs are two sides of the expression
**/
Fraction operator+( const Fraction& lhs, const Fraction& rhs );
Fraction operator-( const Fraction& lhs, const Fraction& rhs );
Fraction operator*( const Fraction& lhs, const Fraction& rhs );
Fraction operator/( const Fraction& lhs, const Fraction& rhs );

using namespace std;

class ExpressionAtom {
    public:
        enum AtomType {
            UNDEFINED =0x0,
            INTEGER_OPERAND,
            FLOAT_OPERAND,
            FRACTION_OPERAND,
            NAMED_OPERAND, // Variable
            OPERATOR,
            FUNCTION
        };

        enum OperatorType {
            SUM,
            DIFFERENCE,
            PRODUCT,
            DIVISION,
            EXPONENT
```

```
62          };
63
64          enum Function {
65              SIN,
66              COS,
67              TAN,
68              LOG,
69              LN,
70              SQRT,
71              ABS,
72              E,
73              PI,
74              UNARY_MINUS
75          };
76
77          /**
78           * @function  ExpressionAtom( )
79           * @abstract  Constructor, defines an ExpressionAtom for various types
80           * @param     Either one of AtomType, OperatorType, Function,
81           *            float, long int, Fraction or string
82           * @post      ExpressionAtom is always valid, containing the
83           *            supplied value. No argument yields UNDEFINED.
84           **/
85          ExpressionAtom( AtomType t =UNDEFINED, long int atom =0l );
86          ExpressionAtom( float atom );
87          ExpressionAtom( long int atom );
88          ExpressionAtom( string var );
89          ExpressionAtom( OperatorType op );
90          ExpressionAtom( Function func );
91          ExpressionAtom( Fraction frac );
92
93          /**
94           * @function  operator==( )
95           * @abstract  Test equality for two ExpressionAtom
96           * @param     ExpressionAtom or either one of AtomType, OperatorType,
97           *            Function, float, long int, Fraction  or string
98           * @return    true upon equality
99           * @post      Two ExpressionAtoms are equal if
100          *            - their types are equal
101          *            - their value is equal
102          *            - they are not UNDEFINED
103          **/
104          bool operator ==( const ExpressionAtom& rhs ) const;
105
106          /**
107          * @function  Inquality operators <, >, <= and >=
108          * @abstract  Test equality for two ExpressionAtoms
109          * @param     ExpressionAtom or either one of AtomType, OperatorType,
110          *            Function, float, long int, Fraction  or string
111          * @return    true upon resp. lt, gt, lte or gte
112          * @pre       Both operands should be of the numeric operand type
113          *            Types do not have to be equal
114          * @post      always false if !isNumericOperand( ) or UNDEFINED
115          **/
```

```
116         bool operator <( const ExpressionAtom& rhs ) const;
117         bool operator >( const ExpressionAtom& rhs ) const;
118         bool operator <=( const ExpressionAtom& rhs ) const;
119         bool operator >=( const ExpressionAtom& rhs ) const;
120
121        /**
122         * @function  Arithmetic operators +, -, *, /
123         * @abstract  Arithmetic result of two ExpressionAtoms
124         * @param     ExpressionAtom or either one of AtomType, OperatorType,
125         *            Function, float, long int, Fraction  or string
126         * @return    ExpressionAtom (xvalue) containing the result
127         *            The type of this ExpressionAtom doesn't need to be
128         *            equal to one of the operand's types
129         * @pre       Both operands should be of the numeric operand type
130         *            Types do not have to be equal
131         * @post      undefined if !isNumericOperand( ) or UNDEFINED
132         **/
133         ExpressionAtom operator+( const ExpressionAtom& rhs ) const;
134         ExpressionAtom operator-( const ExpressionAtom& rhs ) const;
135         ExpressionAtom operator*( const ExpressionAtom& rhs ) const;
136         ExpressionAtom operator/( const ExpressionAtom& rhs ) const;
137
138        /**
139         * @function  pow( )
140         * @abstract  Raise to power
141         * @param     ExpressionAtom or Either one of AtomType, OperatorType,
142         *            Function, float, long int, Fraction  or string
143         * @return    ExpressionAtom (xvalue) containing the result
144         *            The type of this ExpressionAtom doesn't need to be
145         *            equal to one of the operand's types
146         * @pre       Both operands should be of the numeric operand type
147         *            Types do not have to be equal
148         * @post      undefined if !isNumericOperand( ) or UNDEFINED
149         **/
150         ExpressionAtom pow( const ExpressionAtom& power ) const;
151        /**
152         * @function  sqrt( )
153         * @abstract  Square root
154         * @pre       Instance should be of the numeric operand type
155         *            Types do not have to be equal
156         * @return    ExpressionAtom (xvalue) containing the result
157         *            The type of this ExpressionAtom doesn't need to be
158         *            equal to the operand's types
159         * @post      undefined if !isNumericOperand( ) or UNDEFINED
160         **/
161         ExpressionAtom sqrt( ) const;
162
163        /**
164         * @function  setters
165         * @abstract  sets ExpressionAtom to a given value
166         * @param     Either one of AtomType, OperatorType,
167         *            Function, float, long int, Fraction  or string
168         * @post      The type is changed to match the new value
169         **/
```

```
170         void setFloat( float d )
171             { m_type =FLOAT_OPERAND; m_atom.float_atom =std::move( d ); }
172         void setInteger( long int i )
173             { m_type =INTEGER_OPERAND; m_atom.integer_atom =std::move( i ); }
174         void setFraction( const Fraction& frac )
175             { m_type =FRACTION_OPERAND; m_atom.fraction_atom =std::move( frac ); }
176         void setFunction( Function f )
177             { m_type =FUNCTION; m_atom.integer_atom =std::move( f ); }
178         void setOperator( OperatorType op )
179             { m_type =OPERATOR; m_atom.integer_atom =std::move( op ); }
180         void setNamed( string str )
181             { m_type =NAMED_OPERAND; m_named_atom =std::move( str ); }
182
183        /**
184         * @function  getters
185         * @abstract  Return the value as a certain type
186         * @return    Returns the value as the requested type
187         * @pre       Type should match the requested datatype
188         * @post      undefined if type doesn't match or UNDEFINED
189         **/
190         float getFloat( ) const { return m_atom.float_atom; }
191         long int getInteger( ) const { return m_atom.integer_atom; }
192         Fraction getFraction( ) const { return m_atom.fraction_atom; }
193         int getFunction( ) const { return (int)m_atom.integer_atom; }
194         int getOperator( ) const { return (int)m_atom.integer_atom; }
195         string getNamed( ) const { return m_named_atom; }
196
197        /**
198         * @function  isNumericOperand( )
199         * @abstract  Returns whether this instance holds a numeric type
200         * @return    bool with the result
201         **/
202         bool isNumericOperand( ) const {
203             return m_type == FLOAT_OPERAND
204                 || m_type == INTEGER_OPERAND
205                 || m_type == FRACTION_OPERAND; }
206
207        /**
208         * @function  numeric casting functions
209         * @abstract  Casts the value to a certain type
210         * @return    Returns the value as the requested type
211         * @pre       Type should be a numeric operand
212         *            toFloat( ) and toInteger( ) are defined for
213         *            FLOAT_OPERAND, INTEGER_OPERAND and FRACTION_OPERAND
214         *            toFraction( ) is defined for INTEGER_OPERAND and FRACTION
215         * @post      undefined if !isNumericOperand( )
216         **/
217         float toFloat( ) const;
218         long int toInteger( ) const;
219         Fraction toFraction( ) const;
220
221        /**
222         * @function  type( )
223         * @abstract  Gives the specified type
```

```
224         * @return    One of AtomType
225         **/
226         AtomType type( ) const { return m_type; }
227 
228        /**
229         * @function  arity( )
230         * @abstract  Returns the arity of the specified type
231         * @return    Arity ranging from 0 to 2
232         **/
233         short arity( ) const;
234 
235     private:
236         union {
237             long int integer_atom;
238             float float_atom;
239             Fraction fraction_atom;
240         } m_atom;
241         string m_named_atom;
242         AtomType m_type;
243 };
244 
245 /**
246 * @function  operator <<( ostream& out, const ExpressionAtom& atom )
247 * @abstract  Overloads operator<< to support ExpressionAtom
248 * @return    an ostream with the contents of atom inserted
249 **/
250 ostream& operator <<( ostream& out, const ExpressionAtom& atom );
251 
252 #endif
```

6.2 ExpressionAtom.cc

```
1  /**
2   * ExpressionAtom:
3   *
4   * @author  Micky Faas (s1407937)
5   * @author  Lisette de Schipper (s1396250)
6   * @file    ExpressionAtom.cc
7   * @date    26-10-2014
8   **/
9 
10 #include "ExpressionAtom.h"
11 #include "ExpressionTree.h"
12 
13 /* Fraction overloads */
14 
15 bool operator ==( const Fraction& lhs, const Fraction& rhs ) {
16     // This function should be in general namespace
17     return ExpressionTree::compare( (float)lhs.numerator/(float)lhs.denominator,
18                                     (float)rhs.numerator/(float)rhs.denominator );
19 }
20 
21 Fraction operator+( const Fraction& lhs, const Fraction& rhs ) {
22     Fraction f;
```

```
23      if( lhs.denominator == rhs.denominator ) {
24          f.denominator =lhs.denominator;
25          f.numerator =lhs.numerator + rhs.numerator;
26      } else {
27          f.denominator =lhs.denominator * rhs.denominator;
28          f.numerator =lhs.numerator * rhs.denominator
29                      + rhs.numerator * lhs.denominator;
30      }
31      return f;
32  }
33
34  Fraction operator-( const Fraction& lhs, const Fraction& rhs ) {
35      Fraction f;
36      if( lhs.denominator == rhs.denominator ) {
37          f.denominator =lhs.denominator;
38          f.numerator =lhs.numerator - rhs.numerator;
39      } else {
40          f.denominator =lhs.denominator * rhs.denominator;
41          f.numerator =lhs.numerator * rhs.denominator
42                      - rhs.numerator * lhs.denominator;
43      }
44      return f;
45  }
46
47  Fraction operator*( const Fraction& lhs, const Fraction& rhs ) {
48      Fraction f;
49      f.denominator =lhs.denominator * rhs.denominator;
50      f.numerator =lhs.numerator * rhs.numerator;
51      return f;
52  }
53
54  Fraction operator/( const Fraction& lhs, const Fraction& rhs ) {
55      Fraction f;
56      f.denominator =lhs.denominator * rhs.numerator;
57      f.numerator =lhs.numerator * rhs.denominator;
58      return f;
59  }
60
61  /* ExpressionAtom implementation */
62
63  ExpressionAtom::ExpressionAtom( AtomType t, long int atom ) : m_type( t ) {
64      m_atom.integer_atom =std::move( atom );
65  }
66
67  ExpressionAtom::ExpressionAtom( float atom ) : m_type( FLOAT_OPERAND ) {
68      m_atom.float_atom =std::move( atom );
69  }
70
71  ExpressionAtom::ExpressionAtom( long int atom ) : m_type( INTEGER_OPERAND ) {
72      m_atom.integer_atom =std::move( atom );
73  }
74
75  ExpressionAtom::ExpressionAtom( string var ) : m_type( NAMED_OPERAND ) {
76      m_named_atom =std::move( var );
```

```
77  }
78
79  ExpressionAtom::ExpressionAtom( OperatorType op ) : m_type( OPERATOR ) {
80      m_atom.integer_atom =std::move( op );
81  }
82
83  ExpressionAtom::ExpressionAtom( Function func ) : m_type( FUNCTION ) {
84      m_atom.integer_atom =std::move( func );
85  }
86
87  ExpressionAtom::ExpressionAtom( Fraction frac ) : m_type( FRACTION_OPERAND ) {
88      m_atom.fraction_atom =std::move( frac );
89  }
90
91  bool ExpressionAtom::operator ==( const ExpressionAtom& rhs ) const {
92      if( rhs.m_type != m_type )
93          return false;
94      switch( m_type ) {
95          case UNDEFINED:
96              return false;
97          case INTEGER_OPERAND:
98          case OPERATOR:
99          case FUNCTION:
100             return m_atom.integer_atom == rhs.m_atom.integer_atom;
101
102         case FLOAT_OPERAND:
103             return m_atom.float_atom == rhs.m_atom.float_atom;
104
105         case FRACTION_OPERAND:
106             return m_atom.fraction_atom == rhs.m_atom.fraction_atom;
107
108         case NAMED_OPERAND:
109             return m_named_atom == rhs.m_named_atom;
110
111     }
112     return false;
113 }
114
115 bool ExpressionAtom::operator <( const ExpressionAtom& rhs ) const {
116     if( !rhs.isNumericOperand( ) || !isNumericOperand( ) )
117         return false;
118     return toFloat( ) < rhs.toFloat( );
119 }
120
121 bool ExpressionAtom::operator >( const ExpressionAtom& rhs ) const {
122     if( !rhs.isNumericOperand( ) || !isNumericOperand( ) )
123         return false;
124     return toFloat( ) > rhs.toFloat( );
125 }
126
127 bool ExpressionAtom::operator <=( const ExpressionAtom& rhs ) const {
128     if( !rhs.isNumericOperand( ) || !isNumericOperand( ) )
129         return false;
130     return toFloat( ) <= rhs.toFloat( );
```

```
131 }
132
133 bool ExpressionAtom::operator >=( const ExpressionAtom& rhs ) const {
134     if( !rhs.isNumericOperand( ) || !isNumericOperand( ) )
135         return false;
136     return toFloat( ) >= rhs.toFloat( );
137 }
138
139 ExpressionAtom ExpressionAtom::operator+( const ExpressionAtom& rhs ) const {
140     ExpressionAtom a;
141     if( isNumericOperand( ) && rhs.isNumericOperand( ) ) {
142         if( m_type == FLOAT_OPERAND || rhs.m_type == FLOAT_OPERAND )
143             a.setFloat( toFloat( ) + rhs.toFloat( ) );
144         else if( m_type == FRACTION_OPERAND || rhs.m_type == FRACTION_OPERAND )
145             a.setFraction( toFraction( ) + rhs.toFraction( ) );
146         else
147             a.setInteger( getInteger( ) + rhs.getInteger( ) );
148     }
149     return a;
150 }
151
152 ExpressionAtom ExpressionAtom::operator-( const ExpressionAtom& rhs ) const {
153     ExpressionAtom a;
154     if( isNumericOperand( ) && rhs.isNumericOperand( ) ) {
155         if( m_type == FLOAT_OPERAND || rhs.m_type == FLOAT_OPERAND )
156             a.setFloat( toFloat( ) - rhs.toFloat( ) );
157         else if( m_type == FRACTION_OPERAND || rhs.m_type == FRACTION_OPERAND )
158             a.setFraction( toFraction( ) - rhs.toFraction( ) );
159         else
160             a.setInteger( getInteger( ) - rhs.getInteger( ) );
161     }
162     return a;
163 }
164
165 ExpressionAtom ExpressionAtom::operator*( const ExpressionAtom& rhs ) const {
166     ExpressionAtom a;
167     if( isNumericOperand( ) && rhs.isNumericOperand( ) ) {
168         if( m_type == FLOAT_OPERAND || rhs.m_type == FLOAT_OPERAND )
169             a.setFloat( toFloat( ) * rhs.toFloat( ) );
170         else if( m_type == FRACTION_OPERAND || rhs.m_type == FRACTION_OPERAND )
171             a.setFraction( toFraction( ) * rhs.toFraction( ) );
172         else
173             a.setInteger( getInteger( ) * rhs.getInteger( ) );
174     }
175     return a;
176 }
177
178 ExpressionAtom ExpressionAtom::operator/( const ExpressionAtom& rhs ) const {
179     ExpressionAtom a;
180     if( isNumericOperand( ) && rhs.isNumericOperand( ) ) {
181         if( m_type == FLOAT_OPERAND || rhs.m_type == FLOAT_OPERAND )
182             a.setFloat( toFloat( ) / rhs.toFloat( ) );
183         else if( m_type == FRACTION_OPERAND || rhs.m_type == FRACTION_OPERAND )
184             a.setFraction( toFraction( ) / rhs.toFraction( ) );
```

```
185         else
186             a.setInteger( getInteger( ) / rhs.getInteger( ) );
187     }
188     return a;
189 }
190
191 ExpressionAtom ExpressionAtom::pow( const ExpressionAtom& power ) const {
192     ExpressionAtom a;
193     if( isNumericOperand( ) && power.isNumericOperand( ) ) {
194
195         if( power.m_type == FRACTION_OPERAND
196             && power.m_atom.fraction_atom == Fraction( { 1, 2 } ) ) {
197             return sqrt( );
198         }
199         else if( m_type == FLOAT_OPERAND
200             || power.m_type == FLOAT_OPERAND
201             || power.m_type == FRACTION_OPERAND )
202             a.setFloat( ::powf( toFloat( ), power.toFloat( ) ) );
203         else if( m_type == FRACTION_OPERAND ) {
204             Fraction f;
205             f.numerator =m_atom.fraction_atom.numerator;
206             f.denominator =::pow( m_atom.fraction_atom.denominator,
207                                   power.getInteger( ) );
208             a.setFraction( f );
209         }
210         else {
211             if( power.getInteger( ) > 0 )
212                 a.setInteger( ::powl( getInteger( ), power.getInteger( ) ) );
213             else if( power.getInteger( ) == 0 )
214                 a.setInteger( 1 );
215             else {
216                 Fraction f;
217                 f.numerator =1;
218                 f.denominator =::pow( m_atom.integer_atom,
219                                       abs( power.m_atom.integer_atom ) );
220                 a.setFraction( f );
221             }
222         }
223     }
224     return a;
225 }
226
227 ExpressionAtom ExpressionAtom::sqrt( ) const {
228     ExpressionAtom a;
229     if( isNumericOperand( ) ) {
230         if( m_type == FLOAT_OPERAND  ) {
231             a.setFloat( ::sqrtf( toFloat( ) ) );
232         }
233         else if( m_type == FRACTION_OPERAND ) {
234             float f =::sqrtf( (float)m_atom.fraction_atom.denominator );
235             if( ceil( f ) == floor( f ) )
236                 a.setFraction(
237                     Fraction( { m_atom.fraction_atom.numerator, (int)f } ) );
238             else
```

```
239                 a.setFloat( f );
240         }
241         else {
242             float f =::sqrtf( (float)m_atom.integer_atom );
243             if( ceil( f ) == floor( f ) )
244                 a.setInteger( (int)f );
245             else
246                 a.setFloat( f );
247         }
248     }
249     return a;
250 }
251
252 float ExpressionAtom::toFloat( ) const {
253     if( m_type == INTEGER_OPERAND )
254         return (float)m_atom.integer_atom;
255     else if( m_type == FLOAT_OPERAND )
256         return m_atom.float_atom;
257     else if( m_type == FRACTION_OPERAND )
258         return (float)m_atom.fraction_atom.numerator /
259                (float)m_atom.fraction_atom.denominator;
260
261     return float( );
262 }
263 long int ExpressionAtom::toInteger( ) const {
264     if( m_type == INTEGER_OPERAND )
265         return m_atom.integer_atom;
266     else if( m_type == FLOAT_OPERAND )
267         return (long int)m_atom.float_atom;
268     else if( m_type == FRACTION_OPERAND )
269         return m_atom.fraction_atom.numerator /
270                m_atom.fraction_atom.denominator;
271
272     return int( );
273 }
274 Fraction ExpressionAtom::toFraction( ) const {
275     Fraction frac;
276     if( m_type == FRACTION_OPERAND )
277         return m_atom.fraction_atom;
278     else if( m_type == INTEGER_OPERAND ) {
279         frac.numerator =m_atom.integer_atom;
280         frac.denominator =1;
281     }
282     return frac;
283 }
284
285 short ExpressionAtom::arity( ) const {
286     switch( type( ) ) {
287         case ExpressionAtom::INTEGER_OPERAND:
288         case ExpressionAtom::FLOAT_OPERAND:
289         case ExpressionAtom::FRACTION_OPERAND:
290         case ExpressionAtom::NAMED_OPERAND:
291             return 0;
292
```

```
293         case ExpressionAtom::OPERATOR:
294             return 2;
295         case ExpressionAtom::FUNCTION:
296             switch( getFunction( ) ) {
297                 case ExpressionAtom::SIN:
298                 case ExpressionAtom::COS:
299                 case ExpressionAtom::TAN:
300                 case ExpressionAtom::LN:
301                 case ExpressionAtom::SQRT:
302                 case ExpressionAtom::ABS:
303                 case ExpressionAtom::UNARY_MINUS:
304                     return 1;
305                 case ExpressionAtom::E:
306                 case ExpressionAtom::PI:
307                     return 0;
308                 case ExpressionAtom::LOG:
309                     return 2;
310             }
311             break;
312         case ExpressionAtom::UNDEFINED:
313         default:
314             return 0;
315     }
316     return 0;
317 }
318
319 /* General namespace */
320
321 ostream& operator <<( ostream& out, const ExpressionAtom& atom ) {
322     switch( atom.type( ) ) {
323         case ExpressionAtom::INTEGER_OPERAND:
324             out << atom.getInteger( );
325             break;
326         case ExpressionAtom::FLOAT_OPERAND:
327             out << atom.getFloat( );
328             break;
329         case ExpressionAtom::FRACTION_OPERAND:
330             out << atom.getFraction( ).numerator << "/"
331                 << atom.getFraction( ).denominator;
332             break;
333         case ExpressionAtom::NAMED_OPERAND:
334             out << atom.getNamed( );
335             break;
336         case ExpressionAtom::OPERATOR:
337             switch( atom.getOperator( ) ) {
338                 case ExpressionAtom::SUM:
339                     out << "+";
340                     break;
341                 case ExpressionAtom::DIFFERENCE:
342                     out << "-";
343                     break;
344                 case ExpressionAtom::PRODUCT:
345                     out << "*";
346                     break;
```

```
347                 case ExpressionAtom::DIVISION:
348                     out << "/";
349                     break;
350                 case ExpressionAtom::EXPONENT:
351                     out << "^";
352                     break;
353             }
354             break;
355         case ExpressionAtom::FUNCTION:
356             switch( atom.getFunction( ) ) {
357                 case ExpressionAtom::SIN:
358                     out << "sin";
359                     break;
360                 case ExpressionAtom::COS:
361                     out << "cos";
362                     break;
363                 case ExpressionAtom::TAN:
364                     out << "tan";
365                     break;
366                 case ExpressionAtom::LOG:
367                     out << "log";
368                     break;
369                 case ExpressionAtom::LN:
370                     out << "ln";
371                     break;
372                 case ExpressionAtom::SQRT:
373                     out << "sqrt";
374                     break;
375                 case ExpressionAtom::ABS:
376                     out << "abs";
377                     break;
378                 case ExpressionAtom::E:
379                     out << "e";
380                     break;
381                 case ExpressionAtom::PI:
382                     out << "pi";
383                     break;
384                 case ExpressionAtom::UNARY_MINUS:
385                     out << "-";
386                     break;
387             }
388             break;
389         case ExpressionAtom::UNDEFINED:
390         default:
391             break;
392     }
393     return out;
394 }
```

6.3 ExpressionTree.h

```
1  /**
2   * ExpressionTree:
3   *
```

```
4   * @author Micky Faas (s1407937)
5   * @author Lisette de Schipper (s1396250)
6   * @file ExpressionTree.h
7   * @date 10-10-2014
8   **/
9
10  #ifndef EXPRESSIONTREE_H
11  #define EXPRESSIONTREE_H
12
13  #include "Tree.h"
14  #include "ExpressionAtom.h"
15  #include <fstream>
16  #include <string>
17  #include <exception>
18  #include <stdexcept>
19  #include <sstream>
20  #include <cmath>
21  #include <map>
22
23  using namespace std;
24
25  class ParserException : public exception
26  {
27      public:
28          ParserException( const string &str ) : s( str ) {}
29          ~ParserException() throw () {}
30          const char* what() const throw() { return s.c_str(); }
31
32      private:
33          string s;
34  };
35
36  class ExpressionTree : public Tree<ExpressionAtom>
37  {
38      public:
39          /**
40           * @function  ExpressionTree( )
41           * @abstract  Constructor, creates an object of the tree.
42           * @post      The tree has been declared.
43           **/
44           ExpressionTree( ) : Tree<ExpressionAtom>() { }
45
46          /**
47           * @function  ExpressionTree( )
48           * @abstract  fromString is called to make a tree from the string.
49           * @param     str, a string that will be parsed to create the three.
50           * @post      The tree has been declared and initialized.
51           **/
52           ExpressionTree( const string& str ) : Tree<ExpressionAtom>() {
53               fromString( str );
54           }
55
56          /**
57           * @function  tokenize( )
```

```
58          * @abstract  Breaks the string provided by fromString up into tokens
59          * @param     str, a string expression
60          * @return    tokenlist, a list of ExpressionAtom's
61          * @pre       str needs to be a correct space-separated string
62          * @post      We have tokens of the string
63          **/
64          static list<ExpressionAtom> tokenize( const string& str );
65
66         /**
67          * @function  fromString( )
68          * @abstract  calls tokenize to generate tokens from an expression and
69          *            fills the ExpressionTree with them.
70          * @param     expression, a string expression
71          * @post      The provided expression will be converted to an
72          *            ExpressionTree if it has the right syntax.
73          **/
74          void fromString( const string& expression );
75
76         /**
77          * @function  differentiate( )
78          * @abstract  calls the other differentiate function and returns the
79          *            derivative in the form of a tree
80          * @param     string varName, the variable
81          * @return    the derivative of the original function in the form of a
82          *            tree
83          * @pre       There needs to be a tree
84          * @post      Derivatree has been changed by the private differentiate
85          *            function.
86          **/
87          ExpressionTree differentiate( string varName );
88
89         /**
90          * @function  simplify( )
91          * @abstract  Performs mathematical simplification on the expression
92          * @post      Upon simplification, nodes may be deleted.
93          *            references and iterators may become invalid
94          **/
95          void simplify( );
96
97         /**
98          * @function  evaluate( )
99          * @abstract  Evaluates the tree as far as possible given a variable and
100         *            its mapping
101         * @return    A new ExpressionTree containing the evaluation (may be a
102         *            single node)
103         * @param     varName, variable name to match (e.g, 'x')
104         * @param     expr, expression to put in place of varName
105         **/
106         ExpressionTree evaluate( string varName, ExpressionAtom expr ) const;
107
108        /**
109         * @function  evaluate( )
110         * @abstract  Evaluates the tree as far as possible using a given mapping
111         * @return    A new ExpressionTree containing the evaluation (may be a
```

```
112          *            single node)
113          * @param     varmap, list of varName/expr pairs
114          **/
115          ExpressionTree evaluate( const map<string,ExpressionAtom>& varmap ) const;
116
117         /**
118          * @function  mapVariable( )
119          * @abstract  Replaces a variable by an expression
120          * @param     varName, variable name to match (e.g, 'x')
121          * @param     expr, expression to put in place of varName
122          * @post      Expression may change, references and iterators
123          *            remain valid after this function.
124          **/
125          void mapVariable( string varName, ExpressionAtom expr );
126
127         /**
128          * @function  mapVariables( )
129          * @abstract  Same as mapVariable( ) for a set of variables/expressions
130          * @param     varmap, list of varName/expr pairs
131          * @post      Expression may change, references and iterators
132          *            remain valid after this function.
133          **/
134          void mapVariables( const map<string,ExpressionAtom>& varmap );
135
136         /**
137          * @function  generateInOrder( )
138          * @abstract  generates the infix notation of the tree.
139          * @param     out, the way in which we want to see the output
140          * @post      The infix notation of the tree has been generated
141          **/
142          void generateInOrder( ostream& out ) const {
143              generateInOrderRecursive( m_root, out );
144          }
145
146      private:
147         /**
148          * @function  differentiate( ), differentiateExponent( ),
149          *            differentiateDivision( ), differentiateProduct( ),
150          *            differentiateFunction( ), differentiateAddition( )
151          * @abstract  differentiates ExpressionTree and places the derivative in
152          *            the tree assigned to the last variable
153          * @param     n, the node we need to start differentiating from
154          * @param     varName, variable name to match (e.g, 'x')
155          * @param     derivative, the node we want to differentiate from
156          * @param     derivatree, the tree we want to differentiate to
157          * @return    the derivative of the original function in the form of a
158          *            tree
159          * @pre       There needs to be a tree
160          * @post      The derivatree has been changed, now it shows the
161          *            derivative of ExpressionTree.
162          **/
163          void differentiate( node_t * n, string varName,
164                              node_t * derivative,
165                              ExpressionTree &derivatree );
```

```
166         void differentiateExponent( node_t * n, string varName,
167                                     node_t * derivative,
168                                     ExpressionTree &derivatree );
169         void differentiateDivision( node_t * n, string varName,
170                                     node_t * derivative,
171                                     ExpressionTree &derivatree );
172         void differentiateProduct( node_t * n, string varName,
173                                    node_t * derivative,
174                                    ExpressionTree &derivatree );
175         void differentiateFunction( node_t * n, string varName,
176                                     node_t * derivative,
177                                     ExpressionTree &derivatree );
178         void differentiateAddition( node_t * n, string varName,
179                                     node_t * derivative,
180                                     ExpressionTree &derivatree );
181
182         /**
183          * @function  simplify( )
184          * @abstract  Performs mathematical simplification on the expression
185          * @param     root, root of the subtree to simplify
186          * @return    New node in place of the passed value/node for root
187          * @post      Upon simplification, nodes may be deleted.
188          *            references and iterators may become invalid
189          **/
190         node_t *simplifyRecursive( node_t* root );
191
192         /**
193          * @function  generateInOrderRecursive( )
194          * @abstract  Recursively goes through the tree to get the infix notation
195          *            of the tree
196          * @param     root, the node we're looking at
197          * @param     buffer, the output
198          * @post      Eventually the infix notation of the tree with parenthesis
199          *            has been generated.
200          **/
201         void generateInOrderRecursive( node_t *root, ostream& buffer ) const;
202
203      public:
204         /**
205          * @function  compare( )
206          * @abstract  Throws a parser expression.
207          * @param     f1, the first value we want to compare
208          * @param     f2, the second value we want to compare
209          * @param     error, the marge in which the difference is accepted.
210          * @return    if the difference between f1 and f2 is smaller or equal to
211          *            error
212          * @post      A ParserException is thrown.
213          **/
214         static bool compare( const float &f1, const float &f2, float &&error =0.00001
215             return ( fabs( f1-f2 ) <= error );
216         }
217
218  };
219  #endif
```

6.4 ExpressionTree.cc

```
/**
 * ExpressionTree:
 *
 * @author  Micky Faas (s1407937)
 * @author  Lisette de Schipper (s1396250)
 * @file    ExpressionTree.cc
 * @date    26-10-2014
 **/

#include "ExpressionTree.h"

list<ExpressionAtom> ExpressionTree::tokenize( const string& str ) {

    list<ExpressionAtom> tokenlist;
    stringstream ss( str );
    while( ss.good( ) ) {
        string token;
        ss >> token;
        ExpressionAtom atom;
        bool unary_minus =false;

        if( token.size( ) > 1 && token[0] == '-' ) {
            token =token.substr( 1 );
            unary_minus =true;
        }

        if( token.find( "." ) != string::npos ) { // Float
            try {
                atom.setFloat( (unary_minus ? -1.0f : 1.0f)
                               * std::stof( token ) );
                unary_minus =false;
            } catch( std::invalid_argument& e ) {
                throw ParserException( string ("Invalid float `")
                                       + token
                                       + string("`") );
            }
        }
        else if( token == "*" )
            atom.setOperator( ExpressionAtom::PRODUCT );
        else if( token == "/" )
            atom.setOperator( ExpressionAtom::DIVISION );
        else if( token == "+" )
            atom.setOperator( ExpressionAtom::SUM );
        else if( token == "-" )
            atom.setOperator( ExpressionAtom::DIFFERENCE );
        else if( token == "^" )
            atom.setOperator( ExpressionAtom::EXPONENT );
        else if( token == "sin" )
            atom.setFunction( ExpressionAtom::SIN );
        else if( token == "cos" )
            atom.setFunction( ExpressionAtom::COS );
        else if( token == "tan" )
```

```
53              atom.setFunction( ExpressionAtom::TAN );
54          else if( token == "ln" )
55              atom.setFunction( ExpressionAtom::LN );
56          else if( token == "log" )
57              atom.setFunction( ExpressionAtom::LOG );
58          else if( token == "sqrt" )
59              atom.setFunction( ExpressionAtom::SQRT );
60          else if( token == "abs" )
61              atom.setFunction( ExpressionAtom::ABS );
62          else if( token == "e" )
63              atom.setFunction( ExpressionAtom::E );
64          else if( token == "pi" )
65              atom.setFunction( ExpressionAtom::PI );
66          else if( token.find( "/" ) != string::npos ) { // Fraction
67              size_t pos =token.find( "/" );
68              Fraction f;
69              try {
70                  f.numerator =(unary_minus ? -1 : 1)
71                              * std::stoi( token.substr( 0, pos ) );
72                  f.denominator =std::stoi( token.substr( pos + 1 ) );
73                  atom.setFraction( f );
74                  unary_minus =false;
75              }
76              catch( std::invalid_argument& e ){
77                  throw ParserException( string ("Invalid fraction `")
78                                         + token
79                                         + string("`") );
80              }
81          }
82          else {
83              try { // Try integer
84                  atom.setInteger( (unary_minus ? -1 : 1) * std::stol( token ) );
85                  unary_minus =false;
86
87              } // Try variable
88              catch( invalid_argument& e ){
89                  for( unsigned int i =0; i < token.size( ); ++i )
90                      if( !isalpha( token[i] ) )
91                          throw ParserException( string ("Invalid token `")
92                                                 + token
93                                                 + string("`") );
94                  atom.setNamed( token );
95              }
96          }
97
98          if( unary_minus )
99              tokenlist.push_back( ExpressionAtom::UNARY_MINUS );
100         tokenlist.push_back( atom );
101     }
102     return tokenlist;
103 }
104
105 void ExpressionTree::fromString( const string& expression ) {
106     list<ExpressionAtom> tokenlist;
```

```
107
108     try{
109         tokenlist =ExpressionTree::tokenize( expression );
110     } catch( ParserException & e ) {
111         throw e;
112     }
113
114     Tree<ExpressionAtom>::node_t *n =0;
115
116     for( auto atom : tokenlist ) {
117         if( !n ) {
118             n =pushBack( atom );
119             continue;
120         }
121         while ( !n->info( ).arity( )
122         || ( n->info( ).arity( ) == 1 && n->hasChildren( ) )
123         || ( n->info( ).arity( ) == 2 && n->isFull( ) ) ) {
124             n =n->parent ( );
125             if( !n )
126                 throw ParserException( "Argument count to arity mismatch" );
127         }
128
129         n =insert( atom, n );
130     }
131 }
132
133 ExpressionTree ExpressionTree::differentiate( string varName ) {
134     ExpressionTree derivatree;
135     differentiate( root( ), varName, derivatree.root( ), derivatree );
136     derivatree.simplify( );
137     return derivatree;
138 }
139
140 void ExpressionTree::simplify( ) {
141     m_root =simplifyRecursive( root( ) );
142 }
143
144 ExpressionTree
145 ExpressionTree::evaluate( string varName, ExpressionAtom expr ) const {
146     ExpressionTree t( *this );
147     t.mapVariable( varName, expr );
148     t.simplify( );
149     return std::move( t );
150 }
151
152 ExpressionTree
153 ExpressionTree::evaluate( const map<string,ExpressionAtom>& varmap ) const {
154     ExpressionTree t( *this );
155     t.mapVariables( varmap );
156     t.simplify( );
157     return std::move( t );
158 }
159
160 void ExpressionTree::mapVariable( string varName, ExpressionAtom expr ) {
```

```
161     map<string,ExpressionAtom> varmap;
162     varmap[varName] =expr;
163     mapVariables( varmap );
164 }
165
166 void ExpressionTree::mapVariables( const map<string,ExpressionAtom>& varmap ) {
167     for( auto &node : *this ) {
168         if( node.info( ).type( ) == ExpressionAtom::NAMED_OPERAND ) {
169             auto it =varmap.find( node.info( ).getNamed( ) );
170             if( it != varmap.cend( ) )
171                 node =it->second;
172         }
173     }
174 }
175
176 void ExpressionTree::differentiate( node_t * n, string varName,
177                                     node_t * derivative,
178                                     ExpressionTree &derivatree ) {
179     ExpressionAtom atom =(*n);
180     switch( atom.type( ) ) {
181         case ExpressionAtom::OPERATOR:
182         switch( atom.getOperator( ) ) {
183             case ExpressionAtom::SUM:
184             case ExpressionAtom::DIFFERENCE:
185                 differentiateAddition( &(*n), varName, derivative, derivatree );
186                 break;
187             case ExpressionAtom::PRODUCT:
188                 differentiateProduct( &(*n), varName, derivative, derivatree );
189                 break;
190             case ExpressionAtom::EXPONENT:
191                 differentiateExponent( &(*n), varName, derivative, derivatree );
192                 break;
193             case ExpressionAtom::DIVISION:
194                 differentiateDivision( &(*n), varName, derivative, derivatree );
195                 break;
196         }
197         break;
198         case ExpressionAtom::FUNCTION:
199             differentiateFunction( &(*n), varName, derivative, derivatree );
200             break;
201         case ExpressionAtom::NAMED_OPERAND:
202             atom.getNamed( ) == string( varName ) ?
203             derivatree.insert( 1L, derivative ) :
204             derivatree.insert( 0L, derivative );
205             break;
206         default:
207             derivatree.insert( 0L, derivative );
208     }
209 }
210
211 void ExpressionTree::differentiateFunction( node_t * n, string varName,
212                                             node_t * derivative,
213                                             ExpressionTree &derivatree ) {
214     Tree<ExpressionAtom> tempTree;
```

```
215     Tree<ExpressionAtom>::node_t *temp;
216     ExpressionAtom atom =(*n);
217     switch( atom.getFunction( ) ){
218         case ExpressionAtom::SIN:
219             temp =derivatree.insert( ExpressionAtom::PRODUCT, derivative );
220             differentiate( (*n).leftChild( ), varName, temp, derivatree );
221             temp =derivatree.insert( ExpressionAtom::COS, temp );
222             copyFromNode( (*n).leftChild( ), temp, true );
223             break;
224         case ExpressionAtom::TAN:;
225             temp =tempTree.insert( ExpressionAtom::DIVISION, tempTree.root( ) );
226             temp =tempTree.insert( ExpressionAtom::SIN, temp );
227             copyFromNode( (*n).leftChild( ), temp, true );
228             temp =temp->parent( );
229             temp =tempTree.insert( ExpressionAtom::COS, temp );
230             copyFromNode( (*n).leftChild( ), temp, true );
231             differentiate( tempTree.root( ), varName, derivative, derivatree );
232             tempTree.clear( );
233             break;
234         case ExpressionAtom::COS:
235             temp =derivatree.insert( ExpressionAtom::PRODUCT, derivative );
236             temp =derivatree.insert( ExpressionAtom::UNARY_MINUS, temp );
237             differentiate( (*n).leftChild( ), varName, temp, derivatree );
238             temp =temp->parent( );
239             temp =derivatree.insert( ExpressionAtom::SIN, temp );
240             copyFromNode( (*n).leftChild( ), temp, true );
241             break;
242         case ExpressionAtom::LN:
243             if( contains( (*n).leftChild( ), string( varName ) ) ) {
244                 temp =derivatree.insert( ExpressionAtom::DIVISION, derivative);
245                 differentiate( (*n).leftChild( ), varName, temp, derivatree );
246                 copyFromNode( (*n).leftChild( ), temp, false );
247             }
248             else
249                 derivatree.insert( 0L, derivative);
250             break;
251         case ExpressionAtom::SQRT:
252             temp =derivatree.insert( ExpressionAtom::DIVISION, derivative );
253             differentiate( (*n).leftChild( ), varName, temp, derivatree );
254             temp =derivatree.insert( ExpressionAtom::PRODUCT, temp );
255             derivatree.insert( 2L, temp );
256             copyFromNode( &(*n), temp, false );
257             break;
258         case ExpressionAtom::LOG:
259             temp =derivatree.insert( ExpressionAtom::PRODUCT, derivative );
260             temp =derivatree.insert( ExpressionAtom::DIVISION, temp );
261             derivatree.insert( 1L, temp);
262             temp =derivatree.insert( ExpressionAtom::LN, temp );
263             copyFromNode( (*n).leftChild( ), temp, true );
264             temp =temp->parent( )->parent( );
265             temp =derivatree.insert( ExpressionAtom::DIVISION, temp );
266             differentiate( (*n).rightChild( ), varName, temp, derivatree );
267             copyFromNode( (*n).rightChild( ), temp, false );
268             break;
```

```
269         case ExpressionAtom::ABS:
270             if( (*n).leftChild( )->info( ).type( ) ==
271                 ExpressionAtom::NAMED_OPERAND &&
272                 (*n).leftChild( )->info( ).getNamed( ) == string( varName ) ) {
273                 temp =derivatree.insert( ExpressionAtom::DIVISION, derivative );
274                 copyFromNode( (*n).leftChild( ), temp, true );
275                 copyFromNode( &(*n), temp, false );
276             }
277             else {
278                 temp =derivatree.insert( ExpressionAtom::DIVISION, derivative );
279                 temp =derivatree.insert( ExpressionAtom::PRODUCT, temp );
280                 copyFromNode( (*n).leftChild( ), temp, true );
281                 differentiate( (*n).leftChild( ), varName, temp, derivatree );
282                 temp =temp->parent( );
283                 copyFromNode( &(*n), temp, false );
284             }
285             break;
286     }
287 }
288
289 void ExpressionTree::differentiateAddition( node_t * n, string varName,
290                                             node_t * derivative,
291                                             ExpressionTree &derivatree ) {
292     Tree<ExpressionAtom>::node_t *temp;
293     ExpressionAtom atom =(*n);
294     if( atom.getOperator( ) == ExpressionAtom::SUM )
295         temp =derivatree.insert( ExpressionAtom::SUM, derivative );
296     else
297         temp =derivatree.insert( ExpressionAtom::DIFFERENCE, derivative );
298     differentiate( (*n).leftChild( ), varName, temp, derivatree );
299     if( (*n).rightChild( ) )
300         differentiate( (*n).rightChild( ), varName, temp, derivatree );
301 }
302
303 void ExpressionTree::differentiateDivision( node_t * n, string varName,
304                                             node_t * derivative,
305                                             ExpressionTree &derivatree ) {
306     Tree<ExpressionAtom>::node_t *temp;
307     temp =derivatree.insert( ExpressionAtom::DIVISION, derivative );
308     temp =derivatree.insert( ExpressionAtom::DIFFERENCE, temp );
309     temp =derivatree.insert( ExpressionAtom::PRODUCT, temp);
310     copyFromNode( (*n).rightChild( ), temp, true );
311     differentiate( (*n).leftChild( ), varName, temp, derivatree );
312     temp =temp->parent( );
313     temp =derivatree.insert( ExpressionAtom::PRODUCT, temp);
314     copyFromNode( (*n).leftChild( ), temp, true );
315     differentiate( (*n).rightChild( ), varName, temp, derivatree );
316     temp =temp->parent( )->parent( );
317     temp =derivatree.insert( ExpressionAtom::EXPONENT, temp );
318     copyFromNode( (*n).rightChild( ), temp, true );
319     derivatree.insert( 2L, temp );
320 }
321
322 void ExpressionTree::differentiateProduct( node_t * n, string varName,
```

```
323                                             node_t * derivative,
324                                             ExpressionTree &derivatree ) {
325     Tree<ExpressionAtom>::node_t *temp;
326     if( (*n).leftChild( )->info( ).isNumericOperand( ) ) {
327         // n * x
328         if( (*n).rightChild( )->info( ).type( ) ==
329             ExpressionAtom::NAMED_OPERAND &&
330             (*n).rightChild( )->info( ).getNamed( ) == string( varName ) )
331             derivatree.insert( (*n).leftChild( )->info( ), derivative );
332         // n * f(x)
333         else {
334             temp =derivatree.insert( ExpressionAtom::PRODUCT, derivative );
335              derivatree.insert( (*n).leftChild( )->info( ), temp );
336              differentiate( (*n).rightChild( ), varName, temp, derivatree );
337         }
338     }
339     else if( (*n).rightChild( )->info( ).isNumericOperand( ) ) {
340         // x * n
341         if( (*n).leftChild( )->info( ).type( ) ==
342             ExpressionAtom::NAMED_OPERAND &&
343             (*n).leftChild( )->info( ).getNamed( ) == string( varName ) )
344             derivatree.insert( (*n).rightChild( )->info( ), derivative );
345         // f(x) * n
346         else {
347             temp =derivatree.insert( ExpressionAtom::PRODUCT, derivative );
348              derivatree.insert( (*n).rightChild( )->info( ), temp );
349              differentiate( (*n).leftChild( ), varName, temp, derivatree );
350         }
351     }
352     // f(x) * g(x)
353     else {
354         temp =derivatree.insert( ExpressionAtom::SUM, derivative );
355         temp =derivatree.insert( ExpressionAtom::PRODUCT, temp );
356         copyFromNode( (*n).rightChild( ), temp, true );
357         differentiate( (*n).leftChild( ), varName, temp, derivatree );
358         temp =temp->parent( );
359         temp =derivatree.insert( ExpressionAtom::PRODUCT, temp );
360         copyFromNode( (*n).leftChild( ), temp, true );
361         differentiate( (*n).rightChild( ), varName, temp, derivatree );
362     }
363 }
364
365 void ExpressionTree::differentiateExponent( node_t * n, string varName,
366                                             node_t * derivative,
367                                             ExpressionTree &derivatree ) {
368     Tree<ExpressionAtom>::node_t *temp;
369     Tree<ExpressionAtom> tempTree;
370     if( contains( (*n).leftChild( ), string( varName ) ) ) {
371         // f(x) ^ g(x)
372         if( contains( (*n).rightChild( ), string( varName ) ) ) {
373             // f(x)^g(x) =e^(ln(f(x))g(x))
374             temp =tempTree.insert( ExpressionAtom::EXPONENT, tempTree.root( ) );
375             tempTree.insert( ExpressionAtom::E, temp );
376             temp =tempTree.insert( ExpressionAtom::PRODUCT, temp );
```

```
377             temp =tempTree.insert( ExpressionAtom::LN, temp );
378             copyFromNode( (*n).leftChild( ), temp, true );
379             temp =temp->parent( );
380             copyFromNode( (*n).rightChild( ), temp, false );
381             differentiate( tempTree.root( ), varName, derivative, derivatree );
382             tempTree.clear( );
383         }
384         // f(x) ^ n
385         else {
386             if( (*n).leftChild( )->info( ).type( ) ==
387                 ExpressionAtom::NAMED_OPERAND &&
388                 (*n).leftChild( )->info( ).getNamed( ) ==
389                 string( varName )  ) {
390                 // x ^ 0
391                 if( (*n).rightChild( )->info( )  == 0L )
392                     derivatree.insert( 1L, derivative );
393                 // x ^ 1
394                 else if( (*n).rightChild( )->info( ) == 1L )
395                     derivatree.insert( string( "x" ), derivative );
396                 // x ^ n ( n > 1 )
397                 else if( (*n).rightChild( )->info( ) > 1L ) {
398                     temp =derivatree.insert( ExpressionAtom::PRODUCT,
399                                              derivative );
400                     derivatree.insert( (*n).rightChild( )->info( ), temp );
401                     temp =derivatree.insert( ExpressionAtom::EXPONENT , temp );
402                     derivatree.insert( string( varName ) , temp );
403                     derivatree.insert( (*n).rightChild( )->info( ) - 1L, temp );
404                 }
405                 // x ^ n ( n < 0 )
406                 else if( (*n).rightChild( )->info( ) < 0L ) {
407                     temp =derivatree.insert( ExpressionAtom::DIVISION,
408                                              derivative);
409                     derivatree.insert( (*n).rightChild( )->info( ), temp );
410                     temp =derivatree.insert( ExpressionAtom::EXPONENT, temp);
411                     derivatree.insert( string( varName ), temp);
412                     derivatree.insert( (*n).rightChild( )->info( ) -
413                                        (*n).rightChild( )->info( ) -
414                                        (*n).rightChild( )->info( ) + 1L, temp);
415                 }
416             }
417             else {
418                 temp =derivatree.insert( ExpressionAtom::PRODUCT, derivative );
419                 temp =derivatree.insert( ExpressionAtom::PRODUCT, temp );
420                 copyFromNode( (*n).rightChild( ), temp, true );
421                 temp =derivatree.insert( ExpressionAtom::EXPONENT, temp );
422                 copyFromNode( (*n).leftChild( ), temp, true );
423                 derivatree.insert( (*n).rightChild( )->info( ) -
424                                    (*n).rightChild( )->info( ) - 1L, temp );
425                 temp =temp->parent( )->parent( );
426                 differentiate( (*n).leftChild( ), varName, temp, derivatree );
427             }
428         }
429     }
430     //e ^ f(x)
```

```
431     else if( (*n).leftChild( )->info( ).type( ) == ExpressionAtom::FUNCTION &&
432              (*n).leftChild( )->info( ).getFunction( ) == ExpressionAtom::E ) {
433         temp =derivatree.insert( ExpressionAtom::PRODUCT, derivative) ;
434         differentiate( (*n).rightChild( ), varName, temp, derivatree );
435         copyFromNode( &(*n), temp, false);
436     }
437     // n ^ f(x)
438     else if( contains( (*n).rightChild( ), string( varName ) ) ) {
439         temp =derivatree.insert( ExpressionAtom::PRODUCT, derivative );
440         temp =derivatree.insert( ExpressionAtom::PRODUCT, temp );
441         differentiate( (*n).rightChild( ), varName, temp, derivatree );
442         temp =derivatree.insert( ExpressionAtom::LN, temp );
443         copyFromNode( (*n).leftChild( ), temp, true );
444         temp =temp->parent( )->parent( );
445         temp =derivatree.insert( ExpressionAtom::EXPONENT, temp );
446         copyFromNode( (*n).leftChild( ), temp, true );
447         copyFromNode( (*n).rightChild( ), temp, false );
448     }
449 }
450
451
452 ExpressionTree::node_t *
453 ExpressionTree::simplifyRecursive( node_t* root ) {
454     if( !root )
455         return 0;
456
457     node_t *n =root->leftChild( );
458     node_t *m =root->rightChild( );
459
460     /* cascade( ): removes root and child n, replaces root with child m */
461     auto cascade =[&]( ) -> node_t* {
462         remove( n );
463         if( root->parent( ) ) {
464             if( root ==root->parent( )->leftChild( ) )
465                 root->parent( )->setLeftChild( m );
466             else
467                 root->parent( )->setRightChild( m );
468             m->setParent( root->parent( ) );
469         }
470         else
471             m->setParent( 0 );
472         delete root;
473         return m;
474     };
475
476     /* merge( ):
477        replaces the root by the result of its operation on the children */
478     auto merge =[&]( ) -> node_t* {
479
480         ExpressionAtom &lhs =root->leftChild( )->info( );
481         ExpressionAtom &rhs =root->rightChild( )->info( );
482         ExpressionAtom &op =root->info( );
483
484         assert( lhs.isNumericOperand( ) && rhs.isNumericOperand( ) );
```

```
485
486         switch( op.getOperator( ) ) {
487             case ExpressionAtom::SUM:
488                 op =std::move( lhs + rhs );
489                 break;
490             case ExpressionAtom::DIFFERENCE:
491                 op =std::move( lhs - rhs );
492                 break;
493             case ExpressionAtom::PRODUCT:
494                 op =std::move( lhs * rhs );
495                 break;
496             case ExpressionAtom::DIVISION:
497                 op =std::move( lhs / rhs );
498                 break;
499             case ExpressionAtom::EXPONENT:
500                 op =std::move( lhs.pow( rhs ) );
501                 break;
502         }
503
504         remove( m );
505         remove( n );
506         return root;
507     };
508
509     /* mergeInto( ): replaces the root by expr and removes the children */
510     auto mergeInto =[&]( ExpressionAtom&& expr ) -> node_t* {
511         remove( m );
512         remove( n );
513         root->info( ) =std::move( expr );
514         return root;
515     };
516
517     bool stop =false;
518     do {
519
520         if( n ) {
521             n =simplifyRecursive( n );
522             if( n && !n->hasChildren( ) ) {
523                 // Simplify the one-fraction
524                 if( n->info( ).type( ) == ExpressionAtom::FRACTION_OPERAND
525                         && n->info( ).getFraction( ).numerator == 1 )
526                     n->info( ).setInteger( 1 );
527
528                 // two operands-case
529                 if( n->info( ).isNumericOperand( )
530                     && m && m->info( ).isNumericOperand( ) ) {
531                     root =merge( );
532                     return root;
533                 }
534
535                 // 1 case
536                 if( n->info( ).isNumericOperand( )
537                     && compare( 1.0f, n->info( ).toFloat( ) ) ) {
538                     if( root->info( ) == ExpressionAtom::PRODUCT ) {
```

```
539                         root =cascade( );
540                     }
541                     else if( root->info( ) == ExpressionAtom::EXPONENT ) {
542                         if( n == root->leftChild( ) )
543                             root =mergeInto( 1l );
544                         else
545                             root =cascade( );
546                     }
547                     else if( root->info( ) == ExpressionAtom::DIVISION ) {
548                         if( n == root->rightChild( ) )
549                             root =cascade( );
550                     }
551                 }
552                 // 0 case
553                 else if( n->info( ).isNumericOperand( )
554                          && compare( 0.0f, n->info( ).toFloat( ) ) ) {
555                     if( root->info( ) == ExpressionAtom::SUM )
556                         root =cascade( );
557                     else if( root->info( ) == ExpressionAtom::PRODUCT ) {
558                         root =mergeInto( 0l );
559                     }
560                     else if( root->info( ) == ExpressionAtom::DIVISION ) {
561                         if( n == root->leftChild( ) )
562                             root =mergeInto( 0l );
563                     }
564                     else if( root->info( ) == ExpressionAtom::DIFFERENCE ) {
565                         if( n == root->rightChild( ) )
566                             root =cascade( );
567                         else if( m && m->info( ).isNumericOperand( ) ) {
568                             root =mergeInto( ExpressionAtom( -1l )
569                                              * m->info( ) );
570                         }
571                     }
572                     else if( root->info( ) == ExpressionAtom::EXPONENT ) {
573                         if( n == root->leftChild( ) ) {
574                             if( m && m->info( ).isNumericOperand( )
575                                   && compare( 1.0f, m->info( ).toFloat( ) ) )
576                                 root =mergeInto( 1l );
577                             else {
578                                 root =mergeInto( 0l );
579                             }
580                         }
581                         else {
582                             root =mergeInto( 1l );
583                         }
584                     }
585                 }
586                 // trivial functions
587                 else if( root->info( ).type( ) == ExpressionAtom::FUNCTION ) {
588                     switch( root->info( ).getFunction( ) ) {
589                         case ExpressionAtom::UNARY_MINUS:
590                             if( n->info( ).isNumericOperand( ) )
591                                 root =mergeInto( ExpressionAtom( -1l )
592                                                  * n->info( ) );
```

```
593                             break;
594                         case ExpressionAtom::LN: // ln(e)
595                             if( n->info( ) == ExpressionAtom::E )
596                                 root =mergeInto( 1l );
597                             break;
598                     }
599                 }
600             }
601         }
602 
603         if( stop )
604             break;
605 
606         n =root->rightChild( );
607         m =root->leftChild( );
608         stop =true;
609     } while( n );
610 
611 return root;
612 }
613 
614 void
615 ExpressionTree::generateInOrderRecursive( node_t *root, ostream& buffer ) const{
616     if( !root )
617         return;
618 
619     if( root->info( ).type( ) == ExpressionAtom::FUNCTION ) {
    // Function type
620         bool enclose =root->isFull( ) // Only enclose in ( )'s if neccessary
621             || ( root->leftChild( ) && !root->leftChild( )->hasChildren( ) )
622             || ( root->rightChild( ) && !root->rightChild( )->hasChildren( ) );
623 
624         if( root->info( ).getFunction( ) == ExpressionAtom::UNARY_MINUS ) {
625             buffer << '(';
626             enclose =false;
627         }
628 
629         buffer << root->info( );
630 
631         if( enclose )
632             buffer << '(';
633 
634         generateInOrderRecursive( root->leftChild( ), buffer );
635 
636         if( root->isFull( ) ) // Function with two params, otherwise no comma
637             buffer << ',';
638 
639         generateInOrderRecursive( root->rightChild( ), buffer );
640 
641         if( enclose )
642             buffer << ')';
643 
644         if( root->info( ).getFunction( ) == ExpressionAtom::UNARY_MINUS )
645             buffer << ')';
```

```
646     } else {    // Operator+operands type
647         if( root->hasChildren( ) && root != m_root )
648             buffer << '(';
649 
650         generateInOrderRecursive( root->leftChild( ), buffer );
651 
652         if( !(root->info( ) == ExpressionAtom::PRODUCT  // implicit multipl.
653             && root->leftChild( )
654             && root->leftChild( )->info( ).isNumericOperand( ) ) )
655             buffer << root->info( );
656         generateInOrderRecursive( root->rightChild( ), buffer );
657 
658         if( root->hasChildren( ) && root != m_root )
659             buffer << ')';
660     }
661 }
```

6.5 main.cc

```
1  /**
2   * main.cc:
3   *
4   * @author  Micky Faas (s1407937)
5   * @author  Lisette de Schipper (s1396250)
6   * @file    main.cc
7   * @date    26-10-2014
8   **/
9 
10 #include <iostream>
11 #include "BinarySearchTree.h"
12 #include "Tree.h"
13 #include "AVLTree.h"
14 #include "SplayTree.h"
15 #include "Treap.h"
16 #include <string>
17 
18 using namespace std;
19 
20 // Makkelijk voor debuggen, moet nog beter
21 template<class T> void printTree( Tree<T> tree, int rows ) {
22     typename Tree<T>::nodelist list =tree.row( 0 );
23     int row =0;
24     while( !list.empty( ) && row < rows ) {
25         string offset;
26         for( int i =0; i < ( 1 << (rows - row) ) - 1 ; ++i )
27             offset += ' ';
28 
29 
30         for( auto it =list.begin( ); it != list.end( ); ++it ) {
31             if( *it )
32                 cout << offset << (*it)->info() << " " << offset;
33             else
34                 cout << offset << ". " << offset;
35         }
```

```
36          cout << endl;
37          row++;
38          list =tree.row( row );
39      }
40  }
41
42  int main ( int argc, char **argv ) {
43
44      /* BST hieronder */
45
46      cout << "BST:" << endl;
47      BinarySearchTree<int> bst;
48
49     /* auto root =bst.pushBack( 10 );
50      bst.pushBack( 5 );
51      bst.pushBack( 15 );
52
53      bst.pushBack( 25 );
54      bst.pushBack( 1 );
55      bst.pushBack( -1 );
56      bst.pushBack( 11 );
57      bst.pushBack( 12 );*/
58
59      Tree<int>* bstP =&bst; // Dit werkt gewoon :-)
60
61      auto root =bstP->pushBack( 10 );
62      bstP->pushBack( 5 );
63      bstP->pushBack( 15 );
64
65      bstP->pushBack( 25 );
66      bstP->pushBack( 1 );
67      bstP->pushBack( -1 );
68      bstP->pushBack( 11 );
69      bstP->pushBack( 12 );
70
71      //printTree<int>( bst, 5 );
72
73
74      //bst.remove( bst.find( 0, 15 ) );
75      //bst.replace( -2, bst.find( 0, 5 ) );
76
77
78      printTree<int>( bst, 5 );
79
80      bst.remove( root );
81
82
83      printTree<int>( bst, 5 );
84
85      /* Splay Trees hieronder */
86
87      cout << "Splay Boom:" << endl;
88      SplayTree<int> splay;
89
```

```
90      splay.pushBack( 10 );
91      auto a =splay.pushBack( 5 );
92      splay.pushBack( 15 );
93
94      splay.pushBack( 25 );
95      auto b =splay.pushBack( 1 );
96      splay.pushBack( -1 );
97      auto c =splay.pushBack( 11 );
98      splay.pushBack( 12 );
99
100     //printTree<int>( splay, 5 );
101
102     //a->swapWith( b );
103     //splay.remove( splay.find( 0, 15 ) );
104     //splay.replace( -2, splay.find( 0, 5 ) );
105
106
107     printTree<int>( splay, 5 );
108
109     //splay.remove( root );
110
111     splay.splay( c );
112
113     printTree<int>( splay, 5 );
114
115     // Test AVLTree //
116
117     AVLTree<char> test;
118     test.insert( 'a' );
119     auto d =test.insert( 'b' );
120     test.insert( 'c' );
121     test.insert( 'd' );
122     test.insert( 'e' );
123     test.insert( 'f' );
124     test.insert( 'g' );
125     cout << "AVL Boompje:" << endl;
126     printTree<char>( test, 5 );
127     cout << d->info( ) << " verwijderen: " << endl;
128     test.remove( d );
129     printTree<char>( test, 5 );
130
131     // Test Treap //
132
133     cout << "Treap" << endl;
134
135     Treap<int> testTreap(5);
136     testTreap.insert(2);
137     testTreap.insert(3);
138     auto e =testTreap.insert(4);
139     testTreap.insert(5);
140     printTree<int>( testTreap, 5 );
141     testTreap.remove(e);
142     printTree<int>( testTreap, 5 );
143
```

```
144     return 0;
145 }
```

6.6 Tree.h

```
1  /**
2   * Tree:
3   *
4   * @author  Micky Faas (s1407937)
5   * @author  Lisette de Schipper (s1396250)
6   * @file    tree.h
7   * @date    26-10-2014
8   **/
9
10 #ifndef TREE_H
11 #define TREE_H
12 #include "TreeNodeIterator.h"
13 #include <assert.h>
14 #include <list>
15 #include <map>
16
17 using namespace std;
18
19 template <class INFO_T> class SplayTree;
20
21 template <class INFO_T> class Tree
22 {
23     public:
24         enum ReplaceBehavoir {
25             DELETE_EXISTING,
26             ABORT_ON_EXISTING,
27             MOVE_EXISTING
28         };
29
30         typedef TreeNode<INFO_T> node_t;
31         typedef TreeNodeIterator<INFO_T> iterator;
32         typedef TreeNodeIterator_in<INFO_T> iterator_in;
33         typedef TreeNodeIterator_pre<INFO_T> iterator_pre;
34         typedef TreeNodeIterator_post<INFO_T> iterator_post;
35         typedef list<node_t*> nodelist;
36
37        /**
38         * @function  Tree( )
39         * @abstract  Constructor of an empty tree
40         **/
41         Tree( )
42             : m_root( 0 ) {
43         }
44
45        /**
46         * @function  Tree( )
47         * @abstract  Copy-constructor of a tree. The new tree contains the nodes
48         *            from the tree given in the parameter (deep copy)
49         * @param     tree, a tree
```

```
50          **/
51          Tree( const Tree<INFO_T>& tree )
52              : m_root( 0 ) {
53              *this =tree;
54          }
55
56          /**
57          * @function  ~Tree( )
58          * @abstract  Destructor of a tree. Timber.
59          **/
60          ~Tree( ) {
61            clear( );
62          }
63
64         /**
65          * @function  begin_pre( )
66          * @abstract  begin point for pre-order iteration
67          * @return    interator_pre containing the beginning of the tree in
68          *            pre-order
69          **/
70          iterator_pre begin_pre( ) {
71              // Pre-order traversal starts at the root
72              return iterator_pre( m_root );
73            }
74
75         /**
76          * @function  begin( )
77          * @abstract  begin point for a pre-order iteration
78          * @return    containing the beginning of the pre-0rder iteration
79          **/
80          iterator_pre begin( ) {
81              return begin_pre( );
82          }
83
84         /**
85          * @function  end( )
86          * @abstract  end point for a pre-order iteration
87          * @return    the end of the pre-order iteration
88          **/
89          iterator_pre end( ) {
90              return iterator_pre( (node_t*)0 );
91          }
92
93         /**
94          * @function  end_pre( )
95          * @abstract  end point for pre-order iteration
96          * @return    interator_pre containing the end of the tree in pre-order
97          **/
98          iterator_pre end_pre( ) {
99              return iterator_pre( (node_t*)0 );
100         }
101
102        /**
103         * @function  begin_in( )
```

```
104          * @abstract  begin point for in-order iteration
105          * @return    interator_in containing the beginning of the tree in
106          *            in-order
107          **/
108          iterator_in begin_in( ) {
109              if( !m_root )
110                  return end_in( );
111              node_t *n =m_root;
112              while( n->leftChild( ) )
113                  n =n->leftChild( );
114              return iterator_in( n );
115            }
116
117          /**
118           * @function  end_in( )
119           * @abstract  end point for in-order iteration
120           * @return    interator_in containing the end of the tree in in-order
121           **/
122          iterator_in end_in( ) {
123              return iterator_in( (node_t*)0 );
124          }
125
126          /**
127           * @function  begin_post( )
128           * @abstract  begin point for post-order iteration
129           * @return    interator_post containing the beginning of the tree in
130           *            post-order
131           **/
132          iterator_post begin_post( ) {
133              if( !m_root )
134                  return end_post( );
135              node_t *n =m_root;
136              while( n->leftChild( ) )
137                  n =n->leftChild( );
138              return iterator_post( n );
139          }
140
141          /**
142           * @function  end_post( )
143           * @abstract  end point for post-order iteration
144           * @return    interator_post containing the end of the tree in post-order
145           **/
146          iterator_post end_post( ) {
147              return iterator_post( (node_t*)0 );
148          }
149
150          /**
151           * @function  pushBack( )
152           * @abstract  a new TreeNode containing `info` is added to the end
153           *            the node is added to the node that :
154           *               - is in the row as close to the root as possible
155           *               - has no children or only a left-child
156           *               - seen from the right hand side of the row
157           *            this is the `natural` left-to-right filling order
```

```
158          *            compatible with array-based heaps and full b-trees
159          * @param     info, the contents of the new node
160          * @post      A node has been added.
161          **/
162          virtual node_t *pushBack( const INFO_T& info ) {
163              node_t *n =new node_t( info, 0 );
164              if( !m_root ) { // Empty tree, simplest case
165                  m_root =n;
166              }
167              else { // Leaf node, there are two different scenarios
168                  int max =getRowCountRecursive( m_root, 0 );
169                  node_t *parent;
170                  for( int i =1; i <= max; ++i ) {
171
172                      parent =getFirstEmptySlot( i );
173                      if( parent ) {
174                          if( !parent->leftChild( ) )
175                              parent->setLeftChild( n );
176                          else if( !parent->rightChild( ) )
177                              parent->setRightChild( n );
178                          n->setParent( parent );
179                          break;
180                      }
181                  }
182              }
183              return n;
184          }
185
186          /**
187           * @function  insert( )
188           * @abstract  inserts node or subtree under a parent or creates an empty
189           *            root node
190           * @param     info, contents of the new node
191           * @param     parent, parent node of the new node. When zero, the root is
192           *            assumed
193           * @param     alignRight, insert() checks on which side of the parent
194           *            node the new node can be inserted. By default, it checks
195           *            the left side first.
196           *            To change this behavior, set preferRight =true.
197           * @param     replaceBehavior, action if parent already has two children.
198           *            One of:
199           *            ABORT_ON_EXISTING - abort and return zero
200           *            MOVE_EXISTING - make the parent's child a child of the new
201           *                            node, satisfies preferRight
202           *            DELETE_EXISTING - remove one of the children of parent
203           *                              completely also satisfies preferRight
204           * @return    pointer to the inserted TreeNode, if insertion was
205           *            successfull
206           * @pre       If the tree is empty, a root node will be created with info
207           *            as it contents
208           * @pre       The instance pointed to by parent should be part of the
209           *            called instance of Tree
210           * @post      Return zero if no node was created. Ownership is assumed on
211           *            the new node.
```

```
212         *            When DELETE_EXISTING is specified, the entire subtree on
213         *            preferred side may be deleted first.
214         **/
215         virtual node_t* insert( const INFO_T& info,
216                         node_t* parent =0,
217                         bool preferRight =false,
218                         int replaceBehavior =ABORT_ON_EXISTING ) {
219             if( !parent )
220                 parent =m_root;
221 
222             if( !parent )
223                 return pushBack( info );
224 
225             node_t *node =0;
226 
227             if( !parent->leftChild( )
228                   && ( !preferRight || ( preferRight &&
229                         parent->rightChild( ) ) ) ) {
230                 node =new node_t( info, parent );
231                 parent->setLeftChild( node );
232                 node->setParent( parent );
233 
234             } else if( !parent->rightChild( ) ) {
235                 node =new node_t( info, parent );
236                 parent->setRightChild( node );
237                 node->setParent( parent );
238 
239             } else if( replaceBehavior == MOVE_EXISTING ) {
240                 node =new node_t( info, parent );
241                 if( preferRight ) {
242                     node->setRightChild( parent->rightChild( ) );
243                     node->rightChild( )->setParent( node );
244                     parent->setRightChild( node );
245                 } else {
246                     node->setLeftChild( parent->leftChild( ) );
247                     node->leftChild( )->setParent( node );
248                     parent->setLeftChild( node );
249                 }
250 
251             } else if( replaceBehavior == DELETE_EXISTING ) {
252                 node =new node_t( info, parent );
253                 if( preferRight ) {
254                     deleteRecursive( parent->rightChild( ) );
255                     parent->setRightChild( node );
256                 } else {
257                     deleteRecursive( parent->leftChild( ) );
258                     parent->setLeftChild( node );
259                 }
260 
261             }
262             return node;
263         }
264 
265         /**
```

```
266         * @function  replace( )
267         * @abstract  replaces an existing node with a new node
268         * @param     info, contents of the new node
269         * @param     node, node to be replaced. When zero, the root is assumed
270         * @param     alignRight, only for MOVE_EXISTING. If true, node will be
271         *            the right child of the new node. Otherwise, it will be the
272         *            left.
273         * @param     replaceBehavior, one of:
274         *            ABORT_ON_EXISTING - undefined for replace()
275         *            MOVE_EXISTING - make node a child of the new node,
276         *                            satisfies preferRight
277         *            DELETE_EXISTING - remove node completely
278         * @return    pointer to the inserted TreeNode, replace() is always
279         *            successful
280         * @pre       If the tree is empty, a root node will be created with info
281         *            as it contents
282         * @pre       The instance pointed to by node should be part of the
283         *            called instance of Tree
284         * @post      Ownership is assumed on the new node. When DELETE_EXISTING
285         *            is specified, the entire subtree pointed to by node is
286         *            deleted first.
287         **/
288         virtual node_t* replace( const INFO_T& info,
289                                  node_t* node =0,
290                                  bool alignRight =false,
291                                  int replaceBehavior =DELETE_EXISTING ) {
292             assert( replaceBehavior != ABORT_ON_EXISTING );
293
294             node_t *newnode =new node_t( info );
295             if( !node )
296                 node =m_root;
297             if( !node )
298                 return pushBack( info );
299
300             if( node->parent( ) ) {
301                 newnode->setParent( node->parent( ) );
302                 if( node->parent( )->leftChild( ) == node )
303                     node->parent( )->setLeftChild( newnode );
304                 else
305                     node->parent( )->setRightChild( newnode );
306             } else
307                 m_root =newnode;
308
309             if( replaceBehavior == DELETE_EXISTING ) {
310
311                 deleteRecursive( node );
312             }
313             else if( replaceBehavior == MOVE_EXISTING ) {
314                 if( alignRight )
315                     newnode->setRightChild( node );
316                 else
317                     newnode->setLeftChild( node );
318                 node->setParent( newnode );
319             }
```

```
320             return node;
321         }
322
323         /**
324          * @function  remove( )
325          * @abstract  removes and deletes node or subtree
326          * @param     n, node or subtree to be removed and deleted
327          * @post      after remove(), n points to an invalid address
328          **/
329         virtual void remove( node_t *n ) {
330             if( !n )
331                 return;
332             if( n->parent( ) ) {
333                 if( n->parent( )->leftChild( ) == n )
334                     n->parent( )->setLeftChild( 0 );
335                 else if( n->parent( )->rightChild( ) == n )
336                     n->parent( )->setRightChild( 0 );
337             }
338             deleteRecursive( n );
339         }
340
341         /**
342          * @function  clear( )
343          * @abstract  clears entire tree
344          * @pre       tree may be empty
345          * @post      all nodes and data are deallocated
346          **/
347         void clear( ) {
348             deleteRecursive( m_root );
349             m_root =0;
350         }
351
352         /**
353          * @function  empty( )
354          * @abstract  test if tree is empty
355          * @return    true when empty
356          **/
357         bool isEmpty( ) const {
358             return !m_root;
359         }
360
361        /**
362          * @function  root( )
363          * @abstract  returns address of the root of the tree
364          * @return    the adress of the root of the tree is returned
365          * @pre       there needs to be a tree
366          **/
367         node_t* root( ){
368             return m_root;
369         }
370
371         /**
372          * @function  row( )
373          * @abstract  returns an entire row/level in the tree
```

```
374          * @param     level, the desired row. Zero gives just the root.
375          * @return    a list containing all node pointers in that row
376          * @pre       level must be positive or zero
377          * @post
378          **/
379          nodelist row( int level ) {
380              nodelist rlist;
381              getRowRecursive( m_root, rlist, level );
382              return rlist;
383          }
384
385         /**
386          * @function  find( )
387          * @abstract  find the first occurrence of info and returns its node ptr
388          * @param     haystack, the root of the (sub)tree we want to look in
389          *            null if we want to start at the root of the tree
390          * @param     needle, the needle in our haystack
391          * @return    a pointer to the first occurrence of needle
392          * @post      there may be multiple occurrences of needle, we only return
393          *            one. A null-pointer is returned if no needle is found
394          **/
395          virtual node_t* find( node_t* haystack, const INFO_T& needle ) {
396              if( haystack == 0 ) {
397                      if( m_root )
398                          haystack =m_root;
399                      else
400                          return 0;
401              }
402              return findRecursive( haystack, needle );
403          }
404
405         /**
406          * @function  contains( )
407          * @abstract  determines if a certain content (needle) is found
408          * @param     haystack, the root of the (sub)tree we want to look in
409          *            null if we want to start at the root of the tree
410          * @param     needle, the needle in our haystack
411          * @return    true if needle is found
412          **/
413          bool contains( node_t* haystack, const INFO_T& needle ) {
414              return find( haystack, needle );
415          }
416
417         /**
418          * @function  toDot( )
419          * @abstract  writes tree in Dot-format to a stream
420          * @param     out, ostream to write to
421          * @pre       out must be a valid stream
422          * @post      out (file or cout) with the tree in dot-notation
423          **/
424          void toDot( ostream& out, const string & graphName ) {
425              if( isEmpty( ) )
426                  return;
427              map<node_t *, int> adresses;
```

```
428             typename map< node_t *, int >::iterator adrIt;
429             int i =1;
430             int p;
431             iterator_pre it;
432             iterator_pre tempit;
433             adresses[m_root] =0;
434             out << "digraph " << graphName << '{' << endl << '"' << 0 << '"';
435             for( it =begin_pre( ); it != end_pre( ); ++it ) {
436                 adrIt =adresses.find( &(*it) );
437                 if( adrIt == adresses.end( ) ) {
438                     adresses[&(*it)] =i;
439                     p =i;
440                     i ++;
441                 }
442                 if( (&(*it))->parent( ) != &(*tempit) )
443                   out << ';' << endl << '"'
444                       << adresses.find( (&(*it))->parent( ))->second << '"';
445                 if( (&(*it)) != m_root )
446                     out << " -> \"" << p << '"';
447                 tempit =it;
448             }
449             out << ';' << endl;
450             for ( adrIt =adresses.begin( ); adrIt != adresses.end( ); ++adrIt )
451                 out << adrIt->second << " [label=\""
452                     << adrIt->first->info( ) << "\"]";
453             out << '}';
454         }
455
456         /**
457          * @function  copyFromNode( )
458          * @abstract  copies the the node source and its children to the node
459          *            dest
460          * @param     source, the node and its children that need to be copied
461          * @param     dest, the node who is going to get the copied children
462          * @param     left, this is true if it's a left child.
463          * @pre       there needs to be a tree and we can't copy to a root.
464          * @post      the subtree that starts at source is now also a child of
465          *            dest
466          **/
467         void copyFromNode( node_t *source, node_t *dest, bool left ) {
468             if (!source)
469                 return;
470             node_t *acorn =new node_t( dest );
471             if(left) {
472                 if( dest->leftChild( ))
473                     return;
474                 dest->setLeftChild( acorn );
475             }
476             else {
477                 if( dest->rightChild( ))
478                     return;
479                 dest->setRightChild( acorn );
480             }
481             cloneRecursive( source, acorn );
```

```
482         }
483
484         Tree<INFO_T>& operator=( const Tree<INFO_T>& tree ) {
485             clear( );
486             if( tree.m_root ) {
487                 m_root =new node_t( (node_t*)0 );
488                 cloneRecursive( tree.m_root, m_root );
489             }
490             return *this;
491         }
492
493     protected:
494        /**
495         * @function  cloneRecursive( )
496         * @abstract  cloning a subtree to a node
497         * @param     source, the node we want to start the cloning process from
498         * @param     dest, the node we want to clone to
499         * @post      the subtree starting at source is cloned to the node dest
500         **/
501         void cloneRecursive( node_t *source, node_t* dest ) {
502             dest->info() =source->info();
503             if( source->leftChild( ) ) {
504                 node_t *left =new node_t( dest );
505                 dest->setLeftChild( left );
506                 cloneRecursive( source->leftChild( ), left );
507             }
508             if( source->rightChild( ) ) {
509                 node_t *right =new node_t( dest );
510                 dest->setRightChild( right );
511                 cloneRecursive( source->rightChild( ), right );
512             }
513         }
514
515        /**
516         * @function  deleteRecursive( )
517         * @abstract  delete all nodes of a given tree
518         * @param     root, starting point, is deleted last
519         * @post      the subtree has been deleted
520         **/
521         void deleteRecursive( node_t *root ) {
522             if( !root )
523                 return;
524             deleteRecursive( root->leftChild( ) );
525             deleteRecursive( root->rightChild( ) );
526             delete root;
527         }
528
529        /**
530         * @function  getRowCountRecursive( )
531         * @abstract  calculate the maximum depth/row count in a subtree
532         * @param     root, starting point
533         * @param     level, starting level
534         * @return    maximum depth/rows in the subtree
535         **/
```

```
536         int getRowCountRecursive( node_t* root, int level ) {
537             if( !root )
538                 return level;
539             return max(
540                     getRowCountRecursive( root->leftChild( ), level+1 ),
541                     getRowCountRecursive( root->rightChild( ), level+1 ) );
542         }
543
544         /**
545          * @function  getRowRecursive( )
546          * @abstract  compile a full list of one row in the tree
547          * @param     root, starting point
548          * @param     rlist, reference to the list so far
549          * @param     level, how many level still to go
550          * @post      a list of a row in the tree has been made.
551          **/
552         void getRowRecursive( node_t* root, nodelist &rlist, int level ) {
553             // Base-case
554             if( !level ) {
555                 rlist.push_back( root );
556             } else if( root ){
557                 level--;
558                 if( level && !root->leftChild( ) )
559                     for( int i =0; i < (level<<1); ++i )
560                         rlist.push_back( 0 );
561                 else
562                    getRowRecursive( root->leftChild( ), rlist, level );
563
564                 if( level && !root->rightChild( ) )
565                     for( int i =0; i < (level<<1); ++i )
566                         rlist.push_back( 0 );
567                 else
568                     getRowRecursive( root->rightChild( ), rlist, level );
569             }
570         }
571
572         /**
573          * @function  findRecursive( )
574          * @abstract  first the first occurrence of needle and return its node
575          *            ptr
576          * @param     haystack, root of the search tree
577          * @param     needle, copy of the data to find
578          * @return    the node that contains the needle
579          **/
580         node_t *findRecursive( node_t* haystack, const INFO_T &needle ) {
581             if( haystack->info( ) == needle )
582                 return haystack;
583
584             node_t *n =0;
585             if( haystack->leftChild( ) )
586                 n =findRecursive( haystack->leftChild( ), needle );
587             if( !n && haystack->rightChild( ) )
588                 n =findRecursive( haystack->rightChild( ), needle );
589             return n;
```

```
590         }
591
592         friend class TreeNodeIterator_pre<INFO_T>;
593         friend class TreeNodeIterator_in<INFO_T>;
594         friend class SplayTree<INFO_T>;
595         TreeNode<INFO_T> *m_root;
596
597     private:
598         /**
599         * @function  getFirstEmptySlot( )
600         * @abstract  when a row has a continuous empty space on the right,
601         *            find the left-most parent in the above row that has
602         *            at least one empty slot.
603         * @param     level, how many level still to go
604         * @return    the first empty slot where we can put a new node
605         * @pre       level should be > 1
606         **/
607         node_t *getFirstEmptySlot( int level ) {
608             node_t *p =0;
609             nodelist rlist =row( level-1 ); // we need the parents of this level
610             /** changed auto to int **/
611             for( auto it =rlist.rbegin( ); it !=rlist.rend( ); ++it ) {
612                 if( !(*it)->hasChildren( ) )
613                     p =(*it);
614                 else if( !(*it)->rightChild( ) ) {
615                     p =(*it);
616                     break;
617                 } else
618                     break;
619             }
620             return p;
621         }
622 };
623
624 #endif
```

6.7 TreeNode.h

```
1  /**
2   * Treenode:
3   *
4   * @author  Micky Faas (s1407937)
5   * @author  Lisette de Schipper (s1396250)
6   * @file    Treenode.h
7   * @date    26-10-2014
8   **/
9
10 #ifndef TREENODE_H
11 #define TREENODE_H
12
13 using namespace std;
14
15 template <class INFO_T> class Tree;
16 class ExpressionTree;
```

```
17
18  template <class INFO_T> class TreeNode
19  {
20      public:
21         /**
22          * @function  TreeNode( )
23          * @abstract  Constructor, creates a node
24          * @param     info, the contents of a node
25          * @param     parent, the parent of the node
26          * @post      A node has been created.
27          **/
28          TreeNode( const INFO_T& info, TreeNode<INFO_T>* parent =0 )
29              : m_lchild( 0 ), m_rchild( 0 ) {
30              m_info =info;
31              m_parent =parent;
32          }
33
34         /**
35          * @function  TreeNode( )
36          * @abstract  Constructor, creates a node
37          * @param     parent, the parent of the node
38          * @post      A node has been created.
39          **/
40          TreeNode( TreeNode<INFO_T>* parent =0 )
41              : m_lchild( 0 ), m_rchild( 0 ) {
42              m_parent =parent;
43          }
44
45         /**
46          * @function  =
47          * @abstract  Sets a nodes content to N
48          * @param     n, the contents you want the node to have
49          * @post      The node now has those contents.
50          **/
51          void operator =( INFO_T n ) { m_info =n; }
52
53         /**
54          * @function  INFO_T( ), info( )
55          * @abstract  Returns the content of a node
56          * @return    m_info, the contents of the node
57          **/
58          operator INFO_T( ) const { return m_info; }
59          const INFO_T &info( ) const { return m_info; }
60          INFO_T &info( ) { return m_info; }
61          /**
62          * @function  atRow( )
63          * @abstract  returns the level or row-number of this node
64          * @return    row, an int of row the node is at
65          **/
66          int atRow( ) const {
67              const TreeNode<INFO_T> *n =this;
68              int row =0;
69              while( n->parent( ) ) {
70                  n =n->parent( );
```

```
71                  row++;
72              }
73              return row;
74          }
75
76          /**
77           * @function  parent( ), leftChild( ), rightChild( )
78           * @abstract  returns the adress of the parent, left child and right
79           *            child respectively
80           * @return    the adress of the requested family member of the node
81           **/
82          TreeNode<INFO_T> *parent( ) const { return m_parent; }
83          TreeNode<INFO_T> *leftChild( ) const { return m_lchild; }
84          TreeNode<INFO_T> *rightChild( ) const { return m_rchild; }
85
86          /**
87           * @function  swapWith( )
88           * @abstract  Swaps this node with another node in the tree
89           * @param     n, the node to swap this one with
90           * @pre       both this node and n must be in the same parent tree
91           * @post      n will have the parent and children of this node
92           *            and vice verse. Both nodes retain their data.
93           **/
94          void swapWith( TreeNode<INFO_T>* n ) {
95              bool this_wasLeftChild =false, n_wasLeftChild =false;
96              if( parent( ) && parent( )->leftChild( ) == this )
97                  this_wasLeftChild =true;
98              if( n->parent( ) && n->parent( )->leftChild( ) == n )
99                  n_wasLeftChild =true;
100
101             // Swap the family info
102             TreeNode<INFO_T>* newParent =
103                 ( n->parent( ) == this ) ? n : n->parent( );
104             TreeNode<INFO_T>* newLeft =
105                 ( n->leftChild( ) == this ) ? n :n->leftChild( );
106             TreeNode<INFO_T>* newRight =
107                  ( n->rightChild( ) == this ) ? n :n->rightChild( );
108
109             n->setParent( parent( ) == n ? this : parent( ) );
110             n->setLeftChild( leftChild( ) == n ? this : leftChild( ) );
111             n->setRightChild( rightChild( ) == n ? this : rightChild( ) );
112
113             setParent( newParent );
114             setLeftChild( newLeft );
115             setRightChild( newRight );
116
117             // Restore applicable pointers
118             if( n->leftChild( ) )
119                 n->leftChild( )->setParent( n );
120             if( n->rightChild( ) )
121                 n->rightChild( )->setParent( n );
122             if( leftChild( ) )
123                 leftChild( )->setParent( this );
124             if( rightChild( ) )
```

```
125                 rightChild( )->setParent( this );
126             if( n->parent( ) ) {
127                 if( this_wasLeftChild )
128                     n->parent( )->setLeftChild( n );
129                 else
130                     n->parent( )->setRightChild( n );
131             }
132             if( parent( ) ) {
133                 if( n_wasLeftChild )
134                     parent( )->setLeftChild( this );
135                 else
136                     parent( )->setRightChild( this );
137             }
138         }
139
140         /**
141         * @function  replace( )
142         * @abstract  Replaces the node with another node in the tree
143         * @param     n, the node we replace the node with, this one gets deleted
144         * @pre       both this node and n must be in the same parent tree
145         * @post      The node will be replaced and n will be deleted.
146         **/
147         void replace( TreeNode<INFO_T>* n ) {
148             bool n_wasLeftChild =false;
149
150             if( n->parent( ) && n->parent( )->leftChild( ) == n )
151                 n_wasLeftChild =true;
152
153             // Swap the family info
154             TreeNode<INFO_T>* newParent =
155                 ( n->parent( ) == this ) ? n : n->parent( );
156             TreeNode<INFO_T>* newLeft =
157                 ( n->leftChild( ) == this ) ? n :n->leftChild( );
158             TreeNode<INFO_T>* newRight =
159                  ( n->rightChild( ) == this ) ? n :n->rightChild( );
160
161             setParent( newParent );
162             setLeftChild( newLeft );
163             setRightChild( newRight );
164             m_info = n->m_info;
165
166             // Restore applicable pointers
167             if( leftChild( ) )
168                 leftChild( )->setParent( this );
169             if( rightChild( ) )
170                 rightChild( )->setParent( this );
171
172             if( parent( ) ) {
173                 if( n_wasLeftChild )
174                     parent( )->setLeftChild( this );
175                 else
176                     parent( )->setRightChild( this );
177             }
178             delete n;
```

```
179         }
180
181         /**
182         * @function  sibling( )
183         * @abstract  returns the address of the sibling
184         * @return    the address to the sibling or zero if there is no sibling
185         **/
186         TreeNode<INFO_T>* sibling( ) {
187             if( parent( )->leftChild( ) == this )
188                 return parent( )->rightChild( );
189             else if( parent( )->rightChild( ) == this )
190                 return parent( )->leftChild( );
191             else
192                 return 0;
193         }
194
195        /**
196         * @function  hasChildren( ), hasParent( ), isFull( )
197         * @abstract  Returns whether the node has children, has parents or is
198         *            full (has two children) respectively
199         * @param
200         * @return    true or false, depending on what is requested from the node.
201         *            if hasChildren is called and the node has children, it will
202         *            return true, otherwise false.
203         *            If hasParent is called and the node has a parent, it will
204         *            return true, otherwise false.
205         *            If isFull is called and the node has two children, it will
206         *            return true, otherwise false.
207         **/
208         bool hasChildren( ) const { return m_lchild || m_rchild; }
209         bool hasParent( ) const { return m_parent; }
210         bool isFull( ) const { return m_lchild && m_rchild; }
211
212     protected:
213         friend class Tree<INFO_T>;
214         friend class ExpressionTree;
215
216        /**
217         * @function  setParent( ), setLeftChild( ), setRightChild( )
218         * @abstract  sets the parent, left child and right child of the
219         *            particular node respectively
220         * @param     p, the node we want to set a certain family member of
221         * @return    void
222         * @post      The node now has a parent, a left child or a right child
223         *            respectively.
224         **/
225         void setParent( TreeNode<INFO_T> *p ) { m_parent =p; }
226         void setLeftChild( TreeNode<INFO_T> *p ) { m_lchild =p; }
227         void setRightChild( TreeNode<INFO_T> *p ) { m_rchild =p; }
228
229     private:
230         INFO_T m_info;
231         TreeNode<INFO_T> *m_parent;
232         TreeNode<INFO_T> *m_lchild;
```

```
233         TreeNode<INFO_T> *m_rchild;
234 };
235
236 /**
237 * @function  <<
238 * @abstract  the contents of the node are returned
239 * @param     out, in what format we want to get the contents
240 * @param     rhs, the node of which we want the contents
241 * @return    the contents of the node.
242 **/
243 template <class INFO_T> ostream &operator <<(ostream& out, const TreeNode<INFO_T> & r
244     out << rhs.info( );
245     return out;
246 }
247
248 #endif
```

6.8 TreeNodeIterator.h

```
1  /**
2   * TreeNodeIterator: Provides a set of iterators that follow the STL-standard
3   *
4   * @author  Micky Faas (s1407937)
5   * @author  Lisette de Schipper (s1396250)
6   * @file    TreeNodeIterator.h
7   * @date    26-10-2014
8   **/
9
10 #include <iterator>
11 #include "TreeNode.h"
12
13 template <class INFO_T> class TreeNodeIterator
14                         : public std::iterator<std::forward_iterator_tag,
15                                                TreeNode<INFO_T>> {
16     public:
17         typedef TreeNode<INFO_T> node_t;
18
19         /**
20          * @function  TreeNodeIterator( )
21          * @abstract  (copy)constructor
22          * @pre       TreeNodeIterator is abstract and cannot be constructed
23          **/
24          TreeNodeIterator( node_t* ptr =0 ) : p( ptr ) { }
25          TreeNodeIterator( const TreeNodeIterator& it ) : p( it.p ) { }
26
27         /**
28          * @function  (in)equality operator overload
29          * @abstract  Test (in)equality for two TreeNodeIterators
30          * @param     rhs, right-hand side of the comparison
31          * @return    true if both iterators point to the same node (==)
32          *            false if both iterators point to the same node (!=)
33          **/
34          bool operator == (const TreeNodeIterator& rhs) { return p==rhs.p; }
35          bool operator != (const TreeNodeIterator& rhs) { return p!=rhs.p; }
```

```
36
37          /**
38           * @function  operator*( )
39           * @abstract  Cast operator to node_t reference
40           * @return    The value of the current node
41           * @pre       Must point to a valid node
42           **/
43           node_t& operator*( ) { return *p; }
44
45          /**
46           * @function  operator++( )
47           * @abstract  pre- and post increment operators
48           * @return    TreeNodeIterator that has iterated one step
49           **/
50           TreeNodeIterator &operator++( ) { next( ); return *this; }
51           TreeNodeIterator operator++( int )
52               { TreeNodeIterator tmp( *this ); operator++( ); return tmp; }
53       protected:
54
55          /**
56           * @function  next( ) //(pure virtual)
57           * @abstract  Implement this function to implement your own iterator
58           */
59           virtual bool next( ){ return false; }// =0;
60           node_t *p;
61   };
62
63   template <class INFO_T> class TreeNodeIterator_pre
64                           : public TreeNodeIterator<INFO_T> {
65       public:
66           typedef TreeNode<INFO_T> node_t;
67
68           TreeNodeIterator_pre( node_t* ptr =0 )
69               : TreeNodeIterator<INFO_T>( ptr ) { }
70           TreeNodeIterator_pre( const TreeNodeIterator<INFO_T>& it )
71               : TreeNodeIterator<INFO_T>( it ) { }
72           TreeNodeIterator_pre( const TreeNodeIterator_pre& it )
73               : TreeNodeIterator<INFO_T>( it.p ) { }
74
75           TreeNodeIterator_pre &operator++( ) { next( ); return *this; }
76           TreeNodeIterator_pre operator++( int )
77               { TreeNodeIterator_pre tmp( *this ); operator++( ); return tmp; }
78
79       protected:
80           using TreeNodeIterator<INFO_T>::p;
81
82          /**
83           * @function  next( )
84           * @abstract  Takes one step in pre-order traversal
85           * @return    returns true if such a step exists
86           */
87           bool next( ) {
88               if( !p )
89                   return false;
```

```
90              if( p->hasChildren( ) ) { // a possible child that can be the next
91                  p =p->leftChild( ) ? p->leftChild( ) : p->rightChild( );
92                  return true;
93              }
94              else if( p->hasParent( ) // we have a right brother
95                      && p->parent( )->rightChild( )
96                      && p->parent( )->rightChild( ) != p ) {
97                  p =p->parent( )->rightChild( );
98                  return true;
99              }
100             else if( p->hasParent( ) ) { // just a parent, thus we go up
101                 TreeNode<INFO_T> *tmp =p->parent( );
102                 while( tmp->parent( ) ) {
103                     if( tmp->parent( )->rightChild( )
104                             && tmp->parent( )->rightChild( ) != tmp ) {
105                         p =tmp->parent( )->rightChild( );
106                         return true;
107                     }
108                     tmp =tmp->parent( );
109                 }
110             }
111             // Nothing left
112             p =0;
113             return false;
114         }
115
116 };
117
118 template <class INFO_T> class TreeNodeIterator_in
119                         : public TreeNodeIterator<INFO_T>{
120     public:
121         typedef TreeNode<INFO_T> node_t;
122
123         TreeNodeIterator_in( node_t* ptr =0 )
124             : TreeNodeIterator<INFO_T>( ptr ) { }
125         TreeNodeIterator_in( const TreeNodeIterator<INFO_T>& it )
126             : TreeNodeIterator<INFO_T>( it ) { }
127         TreeNodeIterator_in( const TreeNodeIterator_in& it )
128             : TreeNodeIterator<INFO_T>( it.p ) { }
129
130         TreeNodeIterator_in &operator++( ) { next( ); return *this; }
131         TreeNodeIterator_in operator++( int )
132             { TreeNodeIterator_in tmp( *this ); operator++( ); return tmp; }
133
134     protected:
135         using TreeNodeIterator<INFO_T>::p;
136        /**
137         * @function  next( )
138         * @abstract  Takes one step in in-order traversal
139         * @return    returns true if such a step exists
140         */
141         bool next( ) {
142             if( p->rightChild( ) ) {
143                 p =p->rightChild( );
```

```
144                 while( p->leftChild( ) )
145                     p =p->leftChild( );
146                 return true;
147             }
148             else if( p->parent( ) && p->parent( )->leftChild( ) == p ) {
149                 p =p->parent( );
150                 return true;
151             } else if( p->parent( ) && p->parent( )->rightChild( ) == p ) {
152                 p =p->parent( );
153                 while( p->parent( ) && p == p->parent( )->rightChild( ) ) {
154                     p =p->parent( );
155                 }
156                 if( p )
157                     p =p->parent( );
158                 if( p )
159                     return true;
160                 else
161                     return false;
162             }
163             // Er is niks meer
164             p =0;
165             return false;
166         }
167 };
168
169 template <class INFO_T> class TreeNodeIterator_post
170                         : public TreeNodeIterator<INFO_T>{
171     public:
172         typedef TreeNode<INFO_T> node_t;
173
174         TreeNodeIterator_post( node_t* ptr =0 )
175             : TreeNodeIterator<INFO_T>( ptr ) { }
176         TreeNodeIterator_post( const TreeNodeIterator<INFO_T>& it )
177             : TreeNodeIterator<INFO_T>( it ) { }
178         TreeNodeIterator_post( const TreeNodeIterator_post& it )
179             : TreeNodeIterator<INFO_T>( it.p ) { }
180
181         TreeNodeIterator_post &operator++( ) { next( ); return *this; }
182         TreeNodeIterator_post operator++( int )
183             { TreeNodeIterator_post tmp( *this ); operator++( ); return tmp; }
184
185     protected:
186         using TreeNodeIterator<INFO_T>::p;
187        /**
188         * @function  next( )
189         * @abstract  Takes one step in post-order traversal
190         * @return    returns true if such a step exists
191         */
192         bool next( ) {
193
194             if( p->hasParent( ) // We have a right brother
195                     && p->parent( )->rightChild( )
196                     && p->parent( )->rightChild( ) != p ) {
197                 p =p->parent( )->rightChild( );
```

```
198                 while( p->leftChild( ) )
199                     p =p->leftChild( );
200                 return true;
201             } else if( p->parent( ) ) {
202                 p =p->parent( );
203                 return true;
204             }
205             // Nothing left
206             p =0;
207             return false;
208         }
209 };
```