Tom Manual

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Tom is a software environment for defining transformations. It is built as a language extension which adds new matching primitives to C, Java, and Caml.

In Java for example, the integration is smooth, allowing the use of the Java Runtime Library without any restriction.

The main construct of Tom is `%match`, which is similar to the match primitive found in functional languages: given an object (called subject) and a list of patterns-actions, the match primitive selects the first pattern that matches the subject and performs the associated action. The subject against which we match can be any object, but in practice, this object is usually a tree-based data-structure.

The `%match` construct can be seen as an extension of the classical switch/case construct. The main difference is that the discrimination occurs on a term and not on atomic values like characters or integers: the patterns are used to discriminate and retrieve information from an algebraic data structure. Therefore, Tom is a good language for programming by pattern matching, and it is particularly well-suited for programming various transformations on trees/terms or XML data-structures.

Information on Tom is available at tom.loria.fr.

Writing a good documentation is a difficult task. To help new users, as well as confirmed Tom developers, we have split the documentation into four complementary documents:

- the *guided tour* briefly introduces each Tom construct by a small example.
- the *tutorial* part introduces, using examples, many concepts related to Tom, from simple to complex ones. The goal is to illustrate concepts and ideas introduced by the reference manual.
- the *language* part is a reference manual which describes the constructs, gives their precise syntax and informal semantics. To support the intuition, some examples may be given, but it is by no means a tutorial introduction to the language. This part also introduces the runtime library, which offers support when using Tom.
- the *tools* part describes how to use the Tom system in a production environment. This document explains both, how to install the software, and how to use it.

Here you can find the detailed table of contents:

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Part I

A guided tour of Tom: code examples

We provide here cut and paste examples, each of them illustrates one particular aspect of the Tom language. Every code snippet comes with the command line to compile and execute it along with the associated program output.

Chapter 1

Basic usage: Algebraic terms and Pattern matching

1.1 Algebraic terms in **Java** – %gom

```
// import class.module.types.*  whith lower case names
import algebraic.logic.types.*;

public class Algebraic {

  %gom { // algebraic signature definition
    module Logic
      imports int String
      abstract syntax

      /* P, Q and implies are 'constructors'
         for the 'sort' Proposition */
      Proposition = P(t:Term)
                  | Q(t:Term)
                  | implies(p1:Proposition, p2:Proposition)

      Term = nat(i:int)
           | var(name:String)
           | plus(t1:Term, t2:Term)

  }

  public static void main(String[] args) {
    // ` (backquote) allows to build algebraic terms
    Proposition p = `implies(P(plus(nat(1),nat(2))), Q(var("x")));
    System.out.println(p);

    // constant time equality check thanks to maximal sharing
    Proposition p1 = `Q(nat(3));
    Proposition p2 = `Q(nat(3));
    System.out.println(p1 == p2);
  }
}
```

```
polux@huggy$ tom Algebraic.t && javac Algebraic.java && java Algebraic
implies(P(plus(nat(1),nat(2))),Q(var("x")))
true
```

1.2 A pretty printer – %match

```
import matching.logic.types.*;

public class Matching {

  %gom {
    module Logic
      imports int String
      abstract syntax

      Proposition = P(t:Term)
                  | Q(t:Term)
                  | implies(p1:Proposition, p2:Proposition)

      Term = nat(i:int)
           | var(name:String)
           | plus(t1:Term, t2:Term)

  }

  public static String prettyProposition(Proposition p) {
    // the sort of p is inferred out of the patterns
    %match(p) {
      // variable instances are accessed with `
      P(t)        -> { return "P(" + prettyTerm(`t) + ")"; }
      Q(var("x")) -> { System.out.println("I␣was␣here␣!"); }
      /* since the previous rule does not break the flow (with a return statement),
         tom still looks for matching patterns in their declaration order  */
      Q(t)        -> { return "Q(" + prettyTerm(`t) + ")"; }
      implies(p1,p2) -> { return "(" + prettyProposition(`p1)
                                + "␣=>␣" + prettyProposition(`p2) + ")"; }
    }
    return ""; // this case never occurs, but javac isn't aware of it
  }

  public static String prettyTerm(Term t) {
    %match(t) {
      nat(i) -> { return Integer.toString(`i); }
      var(x) -> { return `x; }
      plus(t1,t2) -> { return prettyTerm(`t1) + "␣+␣" + prettyTerm(`t2); }
    }
    return "";
  }

  public static void main(String[] args) {
    Proposition p = `implies(P(plus(nat(1),nat(2))), Q(var("x")));
    System.out.println(prettyProposition(`p));
  }
}
```

```
polux@huggy$ tom Matching.t && javac Matching.java && java Matching
I was here !
(P(1 + 2) => Q(x))
```

1.3 Antipatterns

```
import anti.cars.types.*;

public class Anti {
```

```
  %gom {
    module Cars
      abstract syntax

      Vehicle = car(interior:Colors, exterior:Colors, type:Type)
              | bike()

      Type = ecological()
           | polluting()

      Colors = red()
             | green()
  }

  /* anti-pattern matching works just like pattern matching
     except that we may introduce complement symbols, denoted by '!',
     in the patterns
      */
  private static void searchCars(Vehicle subject){
    %match(subject){
      !car(x,x,_) -> {
        System.out.println(
            "- Not a car, or car with different colors:\t\t" + `subject);
      }
      car(x,!x,!ecological()) -> {
        System.out.println(
            "- Car that is not ecological and that does not\n"+
            "  have the same interior and exterior colors: \t\t" + `subject);
      }
      car(x@!green(),x,ecological()) -> {
        System.out.println(
            "- Ecological car and that has the same interior\n"+
            "  and exterior colors, but different from green: \t" + `subject);
      }
    }
  }

  public static void main(String[] args) {
    Vehicle veh1 = `bike();
    Vehicle veh2 = `car(red(),green(),ecological());
    Vehicle veh3 = `car(red(),red(),ecological());
    Vehicle veh4 = `car(green(),green(),ecological());
    Vehicle veh5 = `car(green(),red(),polluting());

    searchCars(veh1);
    searchCars(veh2);
    searchCars(veh3);
    searchCars(veh4);
    searchCars(veh5);
  }
}
```

```
polux@huggy$ tom Anti.t && javac Anti.java && java Anti
- Not a car, or car with different colors: bike()
- Not a car, or car with different colors: car(red(),green(),ecological())
- Ecological car and that has the same interior
  and exterior colors, but different from green: car(red(),red(),ecological())
- Not a car, or car with different colors: car(green(),red(),polluting())
- Car that is not ecological and that does not
  have the same interior and exterior colors: car(green(),red(),polluting())
```

1.4 Computing a fixpoint – %strategy, RepeatId

```
import rmdoubles.mylist.types.*;
import tom.library.sl.*; // imports the runtime strategy library

public class RmDoubles {

  // includes description of strategy operators for tom (RepeatId here)
  %include { sl.tom }

  %gom {
    module mylist
      imports  String
      abstract syntax

      StrList = strlist(String*)
  }

  /* we define a 'user strategy' which should be seen as
     a rewrite system (composed of only one rule here) */
  %strategy Remove() extends `Identity() {
    visit StrList { (X*,i,Y*,i,Z*) -> { return `strlist(X*,i,Y*,Z*); } }
  }

  public static void main(String[] args) throws VisitFailure {
    StrList l = `strlist("framboisier","eric","framboisier","remi",
                         "remi","framboisier","rene","bernard");
    System.out.println(l);

    /* We compute a fixpoint for the rewrite system 'Remove'
       applied in head of l thanks to the strategy 'RepeatId'
       which takes another strategy (here Remove) as an
       argument. */
    System.out.println(`RepeatId(Remove()).visit(l));
  }
}
```

```
polux@huggy$ tom RmDoubles.t && javac RmDoubles.java && java RmDoubles
strlist("framboisier","eric","framboisier","remi","remi","framboisier","rene","bernard")
strlist("framboisier","eric","remi","rene","bernard")
```

1.5 An expression evaluator – %strategy, InnerMostId

```
import eval.mydsl.types.*;
import tom.library.sl.*;

public class Eval {

  %include { sl.tom }

  %gom {
    module mydsl
      imports int String
      abstract syntax

      Expr = val(v:int)
           | var(n:String)
           | plus(Expr*)
           | mult(Expr*)
  }
```

```
  /* EvalExpr is a rewrite system which simplifies expressions.
     It is meant to be applied on any sub-expression of a bigger one,
     not only in head. */
  %strategy EvalExpr() extends Identity() {
    visit Expr {
      plus(l1*,val(x),l2*,val(y),l3*) -> { return `plus(l1*,l2*,l3*,val(x + y)); }
      mult(l1*,val(x),l2*,val(y),l3*) -> { return `mult(l1*,l2*,l3*,val(x * y)); }
      plus(v@val(_)) -> { return `v; }
      mult(v@val(_)) -> { return `v; }
    }
  }

  public static void main(String[] args) throws VisitFailure {
    Expr e = `plus(val(2),var("x"),mult(val(3),val(4)),var("y"),val(5));

    /* We choose to apply the rewrite system in an innermost way
       (aka. call by value). The InnermostId strategy does the
       job and stops when a fixpoint is reached.
       Since the visit method of strategies returns a Visitable,
       we have to cast the result. */
    Expr res = (Expr) `InnermostId(EvalExpr()).visit(e);
    System.out.println(e + "\n" + res);
  }
}
```

```
polux@huggy$ tom Eval.t && javac Eval.java && java Eval
plus(val(2),var("x"),mult(val(3),val(4)),var("y"),val(5))
plus(var("x"),var("y"),val(19))
```

1.6 Variable Collector – %strategy with mutable parameters

```
import collect.logic.types.*;
import tom.library.sl.*;
import java.util.LinkedList;
import java.util.HashSet;

public class Collect {

  %include { sl.tom }

  /* Since strategies arguments (Collection c here)
     have to be seen as algebraic terms by tom, we
     include the tom's java Collection description */
  %include { util/types/Collection.tom }

  %gom {
    module logic
      imports String
      abstract syntax

      Term = var(name:String)
           | f(t:Term)

      Prop = P(t: Term)
           | implies(l:Prop, r:Prop)
           | forall(name:String, p:Prop)
  }

  /* This strategy takes a java Collection as an argument
```

```
    and performs some side-effect (add). */
  %strategy CollectVars(Collection c) extends `Identity() {
    visit Term { v@var(_) -> { c.add(`v); } }
  }

  public static void main(String[] args) throws VisitFailure {
    Prop p = `forall("x", implies(implies(P(f(var("x"))), P(var("y"))),P(f(var("y")))));

    /* We choose an HashSet as a collection and we
       apply the collector to the proposition p
       in a TopDown way */
    HashSet result = new HashSet();
    `TopDown(CollectVars(result)).visit(p);
    System.out.println("vars: " + result);
  }
}
```

```
polux@huggy$ tom Collect.t && javac Collect.java && java Collect
vars: [var("x"), var("y")]
```

1.7 Collecting free variables – μ operator, composed strategies

```
import advanced.logic.types.*;
import tom.library.sl.*;
import java.util.LinkedList;

public class Advanced {

  %include { sl.tom }
  %include { util/types/Collection.tom }

  %gom {
    module logic
      imports String
      abstract syntax

      Term = var(name:String)
           | f(t:Term)

      Prop = P(t: Term)
           | implies(l:Prop, r:Prop)
           | forall(name:String, p:Prop)
  }

   /* - If the strategy encounters 'forall name, ...', then it
        returns the identity.
      - If it encounters 'name', then it adds its position to the collection c.
      - By default, it fails. (extends Fails) */
  %strategy CollectFree(String name, Collection c) extends Fail() {
    visit Prop { p@forall(x,_) -> { if(`x == name) return `p; } }
    visit Term { v@var(x)      -> { if(`x == name) c.add(getEnvironment().getPosition()); } }
  }

  private static LinkedList<Position>
    collectFreeOccurences(String name, Prop p) throws VisitFailure {
      LinkedList res = new LinkedList();
      /* This strategy means:
           - try to apply CollectFree on the current term
             - if it worked then stop here
             - else apply yourself (mu operator) on all the
```

```
            subterms of the current term */
      `mu(MuVar("x"), Choice(CollectFree(name,res),All(MuVar("x")))).visit(p);
      return res;
    }

  public static void main(String[] args) throws VisitFailure {
    Prop p = `forall("x", implies(implies(P(f(var("x"))), P(var("y"))),P(f(var("y")))));

    System.out.println("free occurences of x: " + collectFreeOccurences("x",p));
    System.out.println("free occurences of y: " + collectFreeOccurences("y",p));
  }
}
```

```
polux@huggy$ tom Advanced.t && javac Advanced.java && java Advanced
free occurences of x: []
free occurences of y: [[2, 1, 2, 1], [2, 2, 1, 1]]
```

Chapter 2

Data structure invariants: Hooks

2.1 Sorted list – maintaining invariants with rule-based hooks

```
import rules.sortedlist.types.*;

public class Rules {

  %gom {
    module sortedlist
      imports int
      abstract syntax

      Integers = sorted(int*)

      /* we define a normalizing rewrite system
         for the module (only one rule here) */
      module sortedlist:rules() {
        /* everytime a term with 'sorted' as an head symbol
           is constructed, the following conditional rewrite
           rule is applied, hence ensuring an invariant on
           the lists  */
        sorted(x,y,t*) -> sorted(y,x,t*) if y <= x
      }
  }

  public static void main(String[] args) {
    Integers l1 = `sorted(7,5,3,1,9);
    Integers l2 = `sorted(8,4,6,2,0);
    Integers l3 = `sorted(l1*,10,l2*);
    System.out.println(l1 + "\n" + l2 + "\n" + l3);
  }
}
```

```
polux@huggy$ tom Sort.t && javac Sort.java && java Sort
sorted(1,3,5,7,9)
sorted(0,2,4,6,8)
sorted(0,1,2,3,4,5,6,7,8,9,10)
```

2.2 Sorted list revisited – advanced hooks

```
import sort.sortedlist.types.*;

public class Sort {
```

```
  %gom {
    module sortedlist
      imports int
      abstract syntax

      Integers = sorted(int*)

      /* this hook is triggered everytime a term with
         'sorted' as an head symbol is constructed */
      sorted:make_insert(e,l) {
        %match(l) {
          sorted(head,tail*) -> {
            /* The 'realMake' function constructs the
               term without calling the associated hook
               in order to avoid infinite loops. */
            if(e >= `head) {
              // hooks are pure tom-java so we allow any side effect
              System.out.println(e + " is greater than the head of " + `tail);
              return `realMake(head,sorted(e,tail*));
            }
          }
        }
      }
  }

  public static void main(String[] args) {
    Integers l = `sorted(7,5,3,1,9);
    System.out.println(l);
  }
}
```

```
polux@huggy$ tom Sort.t && javac Sort.java && java Sort
3 is greater than the head of sorted(9)
5 is greater than the head of sorted(3,9)
5 is greater than the head of sorted(9)
7 is greater than the head of sorted(3,5,9)
7 is greater than the head of sorted(5,9)
7 is greater than the head of sorted(9)
sorted(1,3,5,7,9)
```

Chapter 3

Seeing Java objects as terms: Mappings

3.1 Matching java.util.LinkedList – standard mappings

```
import java.util.Arrays;
import java.util.LinkedList;

public class Mapping {

  /* includes the mapping for java's LinkedList
     provided with the tom distribution */
  %include{ util/LinkedList.tom }

  public static void main(String[] args) {
    LinkedList<Integer> l = new LinkedList(Arrays.asList(1,2,3,1,4,3,1,1));
    System.out.println("list␣=␣" + l);

    /* We can match linked lists like any other associative constructor.
       Since we declare the Sort (LinkedList) in the %match construct,
       we can use the implicit notation (without the constructor name)
       in the patterns and thus do not need to look at the mapping file. */
    %match(LinkedList l) {
      (_*,x,_*) -> { System.out.println("iterate:␣" + `x); }
      (_*,x,_*,x,_*) -> { System.out.println("appears␣twice:␣" + `x); }
    }
    %match(LinkedList l, LinkedList l) {
      (_*,x,_*), !(_*,x,_*,x,_*) -> { System.out.println("appears␣only␣once:␣" + `x); }
    }
  }
}
```

```
polux@huggy$ tom Mapping.t && javac Mapping.java && java Mapping
list = [1, 2, 3, 1, 4, 3, 1, 1]
iterate: 1
iterate: 2
iterate: 3
iterate: 1
iterate: 4
iterate: 3
iterate: 1
iterate: 1
appears twice: 1
appears twice: 1
```

```
appears twice: 1
appears twice: 3
appears twice: 1
appears twice: 1
appears twice: 1
appears only once: 2
appears only once: 4
```

3.2 Matching cars – Handwritten Mappings

```
public class HandMapping {

  /* We need to include the standard mappings for
     java integers and strings since we declare
     fields of these sorts in the following mapping */
  %include { int.tom }
  %include { string.tom }

  /* This class is here for pedagogic reasons.
     We could have worked with the only 'Car' class */
  private static class Vehicle { }

  /* This demo class declares two fields with
     the corresponding getters and setters, as well
     as a custom version of equals. */
  private static class Car extends Vehicle {
    private int seats = 0;
    private String color = null;

    public Car(int seats, String color) {
      this.seats = seats;
      this.color = color;
    }
    public int getSeats() { return seats; }
    public String getColor() { return color; }
    public void setSeats(int s) { seats = s; }
    public void setColor(String c) { color = c; }
    public boolean equals(Car c) {
      return c.seats == seats && c.color.equals(color);
    }
  }

  /* We define a mapping for the Vehicle and Car classes
     so that it behave like the following gom signature:
     Vehicle = car(seats:int, color:String) */

  // typeterm defines a Sort (Car here)
  %typeterm Vehicle {
    // The corresponding java type
    implement { HandMapping.Car }
    // How to check the sort
    is_sort(c) { c instanceof HandMapping.Car }
    // How to check the equality between two terms of sort Car
    equals(c1,c2) { c1.equals(c2) }
  }

  %op Vehicle car(seats:int, color:String) {
    // Is the head symbol of the tested term a car ?
    is_fsym(c)        { c instanceof Car }
```

```
    // Get the slot name 'seats'
    get_slot(seats,c) { c.getSeats() }
    get_slot(color,c) { c.getColor() }
    // For the ` (backquote) construct
    make(s,c)         { new Car(s,c) }
  }

  /* We can now perform standard term construction
     and pattern matching on vehicles */
  public static void main(String[] args) {
    Vehicle c1 = `car(4,"blue");
    Vehicle c2 = `car(6,"red");
    Vehicle c3 = `car(2,"blue");

    %match (c2) {
      car(s,"red") -> {
        System.out.println("this␣red␣car␣has␣" + `s + "␣seats");
      }
    }
    %match (c1,c3) {
      car(_,c), car(_,c) -> {
        System.out.println("c1␣and␣c3␣have␣the␣same␣" + `c + "␣color");
      }
    }
    %match (Vehicle c1, Vehicle c1) {
      // note that we use the definition of equality here
      x@car(s,c), x -> {
        System.out.println("This␣is␣the␣same␣"+`c +"␣car␣with␣"+`s +"␣seats");
      }
    }
  }
}
```

```
polux@huggy$ tom HandMapping.t && javac HandMapping.java && java HandMapping
this red car has 6 seats
c1 and c3 have the same blue color
This is the same blue car with 4 seats
```

Chapter 4

Term-graph rewriting

Using the Gom option `--termgraph`, it is possible to automatically generate from a signature the extended version for term-graphs. As the Tom terms are implemented with maximal sharing, so are the term-graphs. Term-graphs can be specified using label constructors.

```
import testlist.m.types.*;
import testlist.m.*;
import tom.library.sl.*;
import tom.library.utils.Viewer;

public class TestList {

  %include{sl.tom}

  %gom(--termgraph) {
    module m
      abstract syntax

      Term = a()
           | b()
           | c()
           | d()

      List = doublelinkedlist(previous:List,element:Term,next:List)
           | nil()
           | insert(element:Term,list:List)

      sort List: graphrules(Insert,Identity) {
    l:doublelinkedlist(previous,y,insert(x,v:doublelinkedlist(&l,z,next)))
    ->
    l1:doublelinkedlist(previous,y,
      l2:doublelinkedlist(&l1,x,v:doublelinkedlist(&l2,z,next)))
      }
  }

  public static void main(String[] args) {

    List abcd = (List)
`LabList("1", doublelinkedlist(nil(),a(),
  LabList("2",insert(b(),
    LabList("3",doublelinkedlist(RefList("1"),c(),
      doublelinkedlist(RefList("3"),d(),nil()))))))).expand();
    System.out.println("Original␣subject");
    Viewer.display(abcd);
    System.out.println("Insertion␣with␣term-graph␣rules␣from␣Gom");
    try {
```

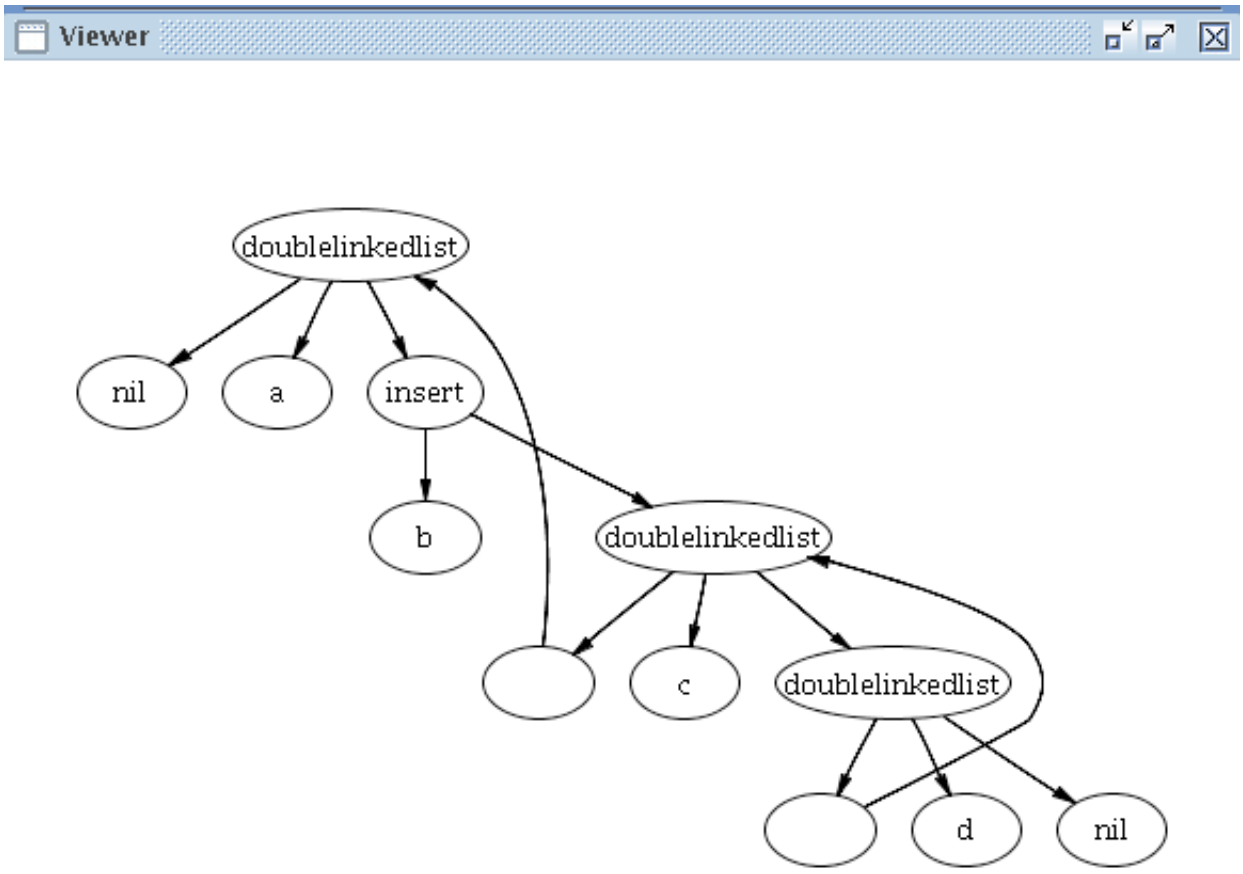
```
      Viewer.display('TopDown(List.Insert()).visit(abcd));
    } catch(VisitFailure e) {
      System.out.println("Unexcepted failure!");
    }
  }

}
```

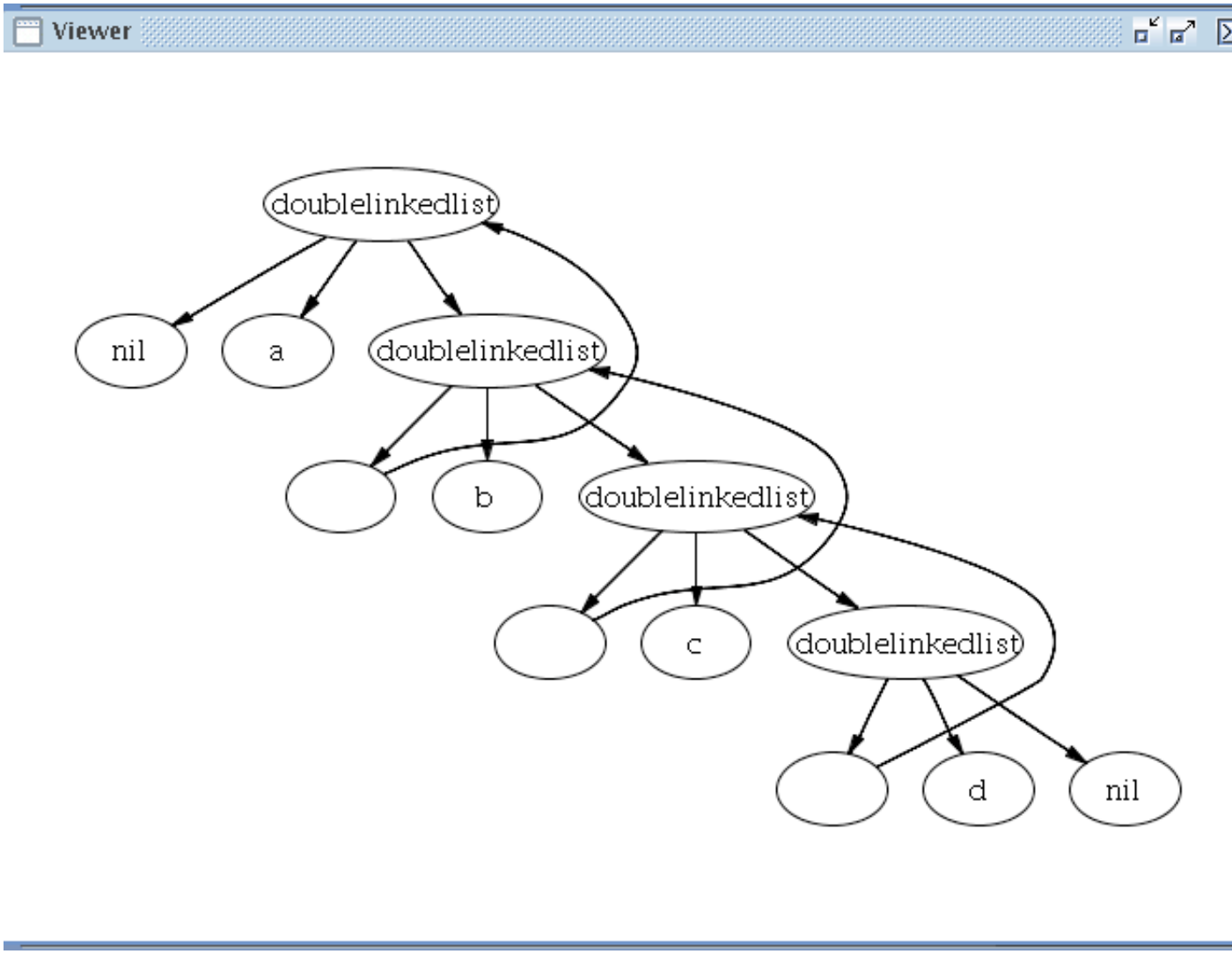
Users can define a system of term-graph rules and it is automatically compiled in a basic Tom strategy. These term-graph rewriting rules can then be integrated in a more complex strategy using Tom strategy combinators. As a consequence, all Tom features are available for term-graphs.

```
polux@huggy$ tom TermList.t && javac TermList.java && java TermList
```

```
Original subject
```




```
Insertion with term-graph rules from Gom
```



This formalism is presented in http://hal.inria.fr/inria-00173535/fr.

Part II

Tutorial

In the following we consider that the reader is familiar with the Java programming language. Since a potential Tom user may have a background very different from another one, we sometimes address a particular topic which may appear too technical or too theoretical. We use (*) and (**) to indicate such sections that may be omitted in the first reading.

Tom is an extension of Java that can be considered as a preprocessor. Therefore, any Java construct can be used in a Tom program. The `tom` command line compiler takes a Tom file, whose extension should be `.t`, and generates a Java file with the extension `.java`. The Java compiler (`javac`) has to be used to produce the class file.

Chapter 5

Language Basics – Level 1

In this first part, we introduce the basic notions provided by Tom: the *definition* of a data-type, the *construction* of data (i.e. trees), and the *transformation* of such data using pattern-matching.

5.1 Defining a data-structure

One of the most simple Tom programs is the following. It defines a data-type to represent Peano integers and builds the integers 0=zero and 1=suc(zero):

```
import main.peano.types.*;

public class Main {
  %gom {
    module Peano
    abstract syntax
    Nat = zero()
        | suc(pred:Nat)
        | plus(x1:Nat, x2:Nat)
   }

  public final static void main(String[] args) {
    Nat z   = `zero();
    Nat one = `suc(z);
    System.out.println(z);
    System.out.println(one);
  }
}
```

The `%gom{ ...}` constructs defines a data-structure, also called signature or algebraic data-type. This data-structure declares a sort (`Nat`) that has three operators (`zero`, `suc`, and `plus`). These operators are called constructors, because they are used to construct the data-structure. `zero` is a constant (arity 0), whereas the arity of `suc` and `plus` is respectively 1 and 2. Note that a name has to be given for each slot (`pred` for suc, and `x1`, `x2` for plus).

Note for the Java programmer: in our terminology, the notion of sort or type (like `Nat`) corresponds to the notion of abstract class. A constructor (such as `zero`, `suc`, or `plus`) can be seen as a class that extends the abstract class. The notion of slot corresponds to a field.

A second construct provided by Tom is the ` (backquote), which builds an object. The expression `` `zero() `` builds the object `zero` of sort `Nat`. This is equivalent to `new zero()`.

In the example, the variable `z` is a Java object that can be used in `` `suc(z) `` to build the object `suc(zero())`. In other words, an algebraic data-structure definition can be seen as a grammar. The ` construct allows to build trees (Abstract Syntax Trees) over this grammar.

The implementation generated by Gom is such that objects can be converted into readable strings, using the `toString()` method.

In the following we assume that Tom is installed, as explained in chapter 14. To run the example, do a copy and paste into `Main.t`, then compile the file using the command: `tom Main.t`. Then, compile the generated Java file: `javac Main.java`, and run it with `java Main`, as shown below:

```
$ tom Main.t
$ javac Main.java
$ java Main
zero()
suc(zero())
```

Note: to use the code generated by a `%gom {...}`, an import statement has to be added: `import main.peano.types.*;`

The path corresponds to the name of the class (`Main`), followed by the name of the module (`Peano`), followed by `types.*`. These package names are in lowercase, even if the class name and the module name contain capitals.

5.2 Retrieving information in a data-structure

In addition to `%gom` and `‘`, Tom provides a third construct: `%match`. Using the same program, we add a method `evaluate(Nat n)` and we modify the method `run()`:

```
import main.peano.types.*;

public class Main {
  %gom {
    module Peano
    abstract syntax
    Nat = zero()
        | suc(pred:Nat)
        | plus(x1:Nat, x2:Nat)
  }

  public final static void main(String[] args) {
    Nat two = ‘plus(suc(zero()),suc(zero()));
    System.out.println(two);
    two = evaluate(two);
    System.out.println(two);
  }

  public static Nat evaluate(Nat n) {
    %match(n) {
      plus(x, zero()) -> { return ‘x; }
      plus(x, suc(y)) -> { return ‘suc(plus(x,y)); }
    }
    return n;
  }
}
```

The `%match` construct is similar to `switch/case` in the sense that given a tree (`n`), the `%match` selects the first pattern that *matches* the tree, and executes the associated action. By *matching*, we mean: giving values to variables to make the pattern equal to the subject. In our example `n` has the value `plus(suc(zero()),suc(zero()))`. The first pattern does not match `n`, because the second subterm of `n` is not a `zero()`, but a `suc(zero())`. In this example, the second pattern matches `n` and gives the value `suc(zero())` to `x`, and `zero()` to `y`.

When a pattern matches a subject, we say that the variables (`x` and `y` in our case) are *instantiated*. They can then be used in the action part (also called right-hand side). Similarly, the second rules can be applied when the second subterm is rooted by a `suc`. In that case, `x` and `y` are instantiated.

The method `evaluate` defines the addition of two integers represented by Peano successors (i.e. `zero` and `suc`). The first case says that the addition of an integer with `zero` is evaluated into the integer itself. The second case builds a new term (rooted by `suc`) whose subterm (`plus(x,y)`) denotes the addition of `x` and `y`.

When executing the program we obtain:

```
plus(suc(zero()),suc(zero()))
suc(plus(suc(zero()),zero()))
```

Note: In a match construct, the variables should not be declared by the programmer. They are written without `()`, and their type is inferred. A variable introduced should be *fresh*: it should not be declared earlier in a wrapping block, either in `Java`, either in a `%match` construct. A Tom variable can be used in the corresponding action, but has to be introduced by a `‘` construct. Note that the scope of a back-quote expression is delimited by well-parenthesized sentences (`‘zero()`, `‘suc(zero())`, `‘suc(x)`). The special case `‘x`, corresponding to a variable alone, is also correct. To write complex expressions, extra parentheses can be added: `‘(x)`, `‘(x == y)` for example.

5.3 Using rules to simplify expressions

In this section, we will show how to use the notion of *rules* to simplify expressions. Suppose that we want to simplify boolean expressions. It is frequent to define the relations between expressions using a set of simplification rules like the following:

$$
\begin{array}{lcl}
Not(a) & \rightarrow & Nand(a,a) \\
Or(a,b) & \rightarrow & Nand(Not(a),Not(b)) \\
And(a,b) & \rightarrow & Not(Nand(a,b)) \\
Xor(a,b) & \rightarrow & Or(And(a,Not(b)),And(Not(a),b)) \\
Nand(True,b) & \rightarrow & True \\
Nand(a,False) & \rightarrow & True \\
Nand(True,True) & \rightarrow & False
\end{array}
$$

To encode such a simplification system, we have to implement a function that simplifies an expression until no more reduction can be performed. This can of course be done using functions defined in `Java`, combined with the `%match` constructs, but it is more convenient to use an algebraic construct that ensures that a rule is applied whenever a reduction is possible. For this purpose, the `%gom` construct provides a `rule()` construct where the left and the right-hand sides are terms. The previous simplification system can be defined as follows:

```
import gates.logic.types.*;

public class Gates {
  %gom {
    module Logic
      imports int
      abstract syntax
      Bool = Input(n:int)
           | True()
           | False()
           | Not(b:Bool)
           | Or(b1:Bool, b2:Bool)
           | And(b1:Bool, b2:Bool)
           | Nand(b1:Bool, b2:Bool)
           | Xor(b1:Bool, b2:Bool)

      module Logic:rules() {
        Not(a)   -> Nand(a,a)
        Or(a,b)  -> Nand(Not(a),Not(b))
```

```
        And(a,b) -> Not(Nand(a,b))
        Xor(a,b) -> Or(And(a,Not(b)),And(Not(a),b))
        Nand(False(),_)     -> True()
        Nand(_,False())     -> True()
        Nand(True(),True()) -> False()
      }
  }

  public final static void main(String[] args) {
    Bool b = `Xor(True(),False());
    System.out.println("b = " + b);
  }
}
```

Note: _ can be used when a specific name for a variable is not needed.

When using the `module Logic:rules() { ... }` constructs, the simplification rules are integrated into the data-structure. This means that the rules are applied any time it is possible to do a reduction. The user does not have any control on them, and thus cannot prevent from applying a rule. Of course, the simplification system should be terminating, otherwise, infinite reductions may occur. When compiling and executing the previous program, we obtain `b = True()`.

5.4 Separating Gom from Tom (*)

Note: do not read this section if you are not interested in separating the data-type definition from the program itself. When programming large applications, it may be more convenient to introduce several classes that share a common data-structure. In that case, the `%gom {...}` construct could be avoided and a Gom file (`Logic.gom` for example) could be used instead:

```
module Logic
imports int
abstract syntax
Bool = Input(n:int)
     | True()
     | False()
     | Not(b:Bool)
     | Or(b1:Bool, b2:Bool)
     | And(b1:Bool, b2:Bool)
     | Nand(b1:Bool, b2:Bool)
     | Xor(b1:Bool, b2:Bool)

module Logic:rules() {
  Not(a)   -> Nand(a,a)
  Or(a,b)  -> Nand(Not(a),Not(b))
  And(a,b) -> Not(Nand(a,b))
  Xor(a,b) -> Or(And(a,Not(b)),And(Not(a),b))

  Nand(False(),_)     -> True()
  Nand(_,False())     -> True()
  Nand(True(),True()) -> False()
}
```

This file can by compiled as follows:

```
$ gom Logic.gom
```

This generates several Java classes, among them a particular file called `Logic.tom` which explains to Tom how the data-structure is implemented. This process is hidden when using the `%gom {...}` construct:

```
$ ls logic
_Logic.tom              Logic.tom               LogicAbstractType.java
strategy                types
```

One of the simplest Tom program that uses the defined data-structure is the following:

```
import logic.types.*;
public class Main {

  %include{ logic/Logic.tom }

  public final static void main(String[] args) {
    Bool b = `Xor(True(),False());
    System.out.println("b = " + b);
  }
}
```

Note: since classes are generated in the `logic` directory, the statement `import logic.types.*;` is needed. The name comes from the name of the module (`Logic`).

In the Tom program, `%include { logic/Logic.tom }` is necessary to include (like a copy and paste) the `Logic.tom` file generated by gom. The `%include` command is similar to the `#include` command provided by the C-preprocessor.

5.5 Programming in Tom

In this section we present how Tom can be used to describe the abstract syntax and to implement an interpreter for a given language. We also give some tips and more information about the generated code.

When using `%gom { ... }`, the generated data-structure is particular: data are maximally shared. This technique, also known as *hash-consing* ensures that two identical subterms are implemented by the same objects. Therefore, the memory footprint is minimal and the equality-check can be done in constant time using the `==` construct (two terms are identical if the pointers are equal). As a consequence, a term is not mutable: once created, it cannot be modified.

Even if the generated API offers getters and setters for each defined slot (`Bool getb1()`, `Bool getb2()`, `Bool setb1(Bool t)` and `Bool setb2(Bool t)` for the `And(b1:Bool,b2:Bool)` defined below). These methods do not really modify the term on which they are applied: `t.setb1(`True())` will return a copy of `t` where the first child is set to `True()`, but the previous `t` is not modified. There is no side-effect in a maximally shared setting.

In Tom, it is quite easy to quickly develop applications which manipulates trees. As an example, let us consider a tiny language composed of boolean expressions (`True`, `False`, `And`, `Or`, and `Not`), expressions (`constant`, `variable`, `Plus`, `Mult`, and `Mod`), and instructions (`Skip`, `Print`, `;`, `If`, and `While`). The abstract syntax of this language can be described as follows:

```
import pico1.term.types.*;
import java.util.*;

class Pico1 {
  %gom {
    module Term
    imports int String
    abstract syntax
    Bool = True()
         | False()
         | Not(b:Bool)
         | Or(b1:Bool, b2:Bool)
         | And(b1:Bool, b2:Bool)
         | Eq(e1:Expr, e2:Expr)
```

```
    Expr = Var(name:String)
         | Cst(val:int)
         | Plus(e1:Expr, e2:Expr)
         | Mult(e1:Expr, e2:Expr)
         | Mod(e1:Expr, e2:Expr)

    Inst = Skip()
         | Assign(name:String, e:Expr)
         | Seq(i1:Inst, i2:Inst)
         | If(cond:Bool, i1:Inst, i2:Inst)
         | While(cond:Bool, i:Inst)
         | Print(e:Expr)
  }
  ...
}
```

Assume that we want to write an interpreter for this language, we need a notion of *environment* to store the value assigned to a variable. A simple solution is to use a `Map` which associate an expression (of sort `Expr`) to a name of variable (of sort `String`). Given this environment, the evaluation of an expression can be implemented as follows:

```
  public static Expr evalExpr(Map env,Expr expr) {
    %match(expr) {
      Var(n)                -> { return (Expr)env.get(‘n); }
      Plus(Cst(v1),Cst(v2)) -> { return ‘Cst(v1 + v2); }
      Mult(Cst(v1),Cst(v2)) -> { return ‘Cst(v1 * v2); }
      Mod(Cst(v1),Cst(v2))  -> { return ‘Cst(v1 % v2); }
      // congruence rules
      Plus(e1,e2) -> { return ‘evalExpr(env,Plus(evalExpr(env,e1),evalExpr(env,e2))); }
      Mult(e1,e2) -> { return ‘evalExpr(env,Mult(evalExpr(env,e1),evalExpr(env,e2))); }
      Mod(e1,e2)  -> { return ‘evalExpr(env,Mod(evalExpr(env,e1),evalExpr(env,e2)));  }

      x -> { return ‘x; }
    }
    throw new RuntimeException("should not be there: " + expr);
  }
```

Note: the congruence rules are needed to enforce reductions in sub-expressions of `Plus`, `Mult`, and `Mod`.

We will see later how they can be avoided using the notion of strategy. Similarly, the evaluation of boolean expressions can be implemented as follows:

```
  public static Bool evalBool(Map env,Bool bool) {
    %match(bool) {
      Not(True())     -> { return ‘False(); }
      Not(False())    -> { return ‘True(); }
      Not(b)          -> { return ‘evalBool(env,Not(evalBool(env,b))); }

      Or(True(),_)    -> { return ‘True(); }
      Or(_,True())    -> { return ‘True(); }
      Or(False(),b2)  -> { return ‘b2; }
      Or(b1,False())  -> { return ‘b1; }
      And(True(),b2)  -> { return ‘b2; }
      And(b1,True())  -> { return ‘b1; }
      And(False(),_)  -> { return ‘False(); }
      And(_,False())  -> { return ‘False(); }

      Eq(e1,e2) -> {
        Expr x = ‘evalExpr(env,e1);
```

```
      Expr y = `evalExpr(env,e2);
      return (x==y)?`True():`False();
    }

    x -> { return `x; }
  }
  throw new RuntimeException("should not be there: " + bool);
}
```

Once defined the methods `evalExpr` and `evalBool`, it becomes easy to define the interpreter:

```
public static void eval(Map env, Inst inst) {
  %match(inst) {
    Skip() -> {
      return;
    }

    Assign(name,e) -> {
      env.put(`name,evalExpr(env,`e));
      return;
    }

    Seq(i1,i2) -> {
      eval(env,`i1);
      eval(env,`i2);
      return;
    }

    Print(e) -> {
      System.out.println(evalExpr(env,`e));
      return;
    }

    If(b,i1,i2) -> {
      if(evalBool(env,`b)==`True()) {
        eval(env,`i1);
      } else {
        eval(env,`i2);
      }
      return;
    }

    w@While(b,i) -> {
      Bool cond = evalBool(env,`b);
      if(cond==`True()) {
        eval(env,`i);
        eval(env,`w);
      }
      return;
    }
  }
  throw new RuntimeException("strange term: " + inst);
}
```

Note: the last two rules use the conditional test `if` from Java to implement a conditional rule.

Note also the use of `w@...` that introduces a variable `w` (an alias). This variable can be used in the

action part to avoid building the term `While(b,i)`. To play with the `Pico` language, we just have to initialize the environment (`env`), create programs (`p1` and `p2`), and evaluate them (`eval`):

```
public final static void main(String[] args) {
  Map env = new HashMap();

  Inst p1 = ‘Seq(Assign("a",Cst(1)) , Print(Var("a")));
  System.out.println("p1: " + p1);
  eval(env,p1);

  Inst p2 = ‘Seq(Assign("i",Cst(0)),
                 While(Not(Eq(Var("i"),Cst(10))),
                       Seq(Print(Var("i")),
                           Assign("i",Plus(Var("i"),Cst(1))))));
  System.out.println("p2: " + p2);
  eval(env,p2);
}
```

Exercise: write a Pico program that computes prime numbers up to 100.

Chapter 6

Language Basics – Level 2

6.1 The "Hello World" example

A very simple program is the following:

```
public class HelloWorld {
  %include { string.tom }

  public final static void main(String[] args) {
    String who = "World";
    %match(who) {
      "World" -> { System.out.println("Hello " + who); }
      _       -> { System.out.println("Don't panic"); }
    }
  }
}
```

The `%include { string.tom }` construct imports the predefined (Java) mapping which defines the Tom `String` algebraic sort. Thus, the sort `String` can be used in the `%match` construct.

This examples shows that pattern matching can be performed against built-in data-types. In this example, the `%match` construct is equivalent to a `switch/case` construct: as expected the first print statement is executed, but the second one is also executed since no `break` statement has been executed.

To use a `break` statement in a `%match` construct, we recommend to use the notion of labeled block:

```
public class HelloWorld {
  %include { string.tom }

  public final static void main(String[] args) {
    String who = "World";
matchblock: {
      %match(who) {
        "World" -> { System.out.println("Hello " + who);
                     break matchblock;
                   }
        _       -> { System.out.println("Don't panic"); }
      }
    }
  }
}
```

6.2 "Hello World" revisited: introduction to list-matching

One particularity of Tom is to simplify the manipulation of lists.

It is natural to consider a string as a list of characters. Characters can be concatenated to from a string, and string can also be concatenated. In Tom, we have to give a name to this concatenation operator. Let us call it `concString`.

Thus, the string ``Hello'' is equivalent to the list of characters `concString('H','e','l','l','o')`. **Note:** `concString` does not have a fixed arity. `concString()` corresponds to the empty list of characters, i.e. the string ``''.

Given a string, to check if the string contains the character 'e', we can use the following matching construct:

```
public class HelloWorld {
  %include { string.tom }
  public final static void main(String[] args) {
    %match("Hello") {
      concString(_*,'e',_*) -> { System.out.println("we have found a 'e'"); }
    }
  }
}
```

In this example, '_*' corresponds to an anonymous variable which can be instantiated by any list of characters (possibly reduced to the empty list).

In order to capture the context (i.e. what is before and after the 'e'), it is possible to use named variables:

```
  %match(t) {
    concString(before*,'e',after*) -> {
      System.out.println("we have found a 'e'" +
                         " after " + `before* +
                         " but before " + `after*);
    }
  }
```

In this example, we have introduced two new variables (`before*` and `after*`), called "variable-star", which are instantiated by a list of characters, instead of a single character (if the '*' was not there).

Suppose now that we look for a word whose last letter is a 'o':

```
  %match(t) {
    concString(before*,'o') -> { ... }
  }
```

Using this mechanism, it also becomes possible to look for a word which contains an 'e' somewhere and an 'o' in last position:

```
  %match(t) {
    concString(before*,'e',_*,'o') -> { ... }
  }
```

Note that a single pattern could provide several outcomes:

```
  %match(t) {
    concString(before*,'l',after*) -> {
      System.out.println("we have found " + `before* +
                         " before 'l' and " + `after* + " after");
    }
  }
```

When applied to ``Hello'', there are two possible solutions for `before*` and `after*`:

```
we have found he before 'l' and lo after
we have found hel before 'l' and o after
```

Let us suppose that we look for two consecutive 'l' anywhere in the matched expression. This could be expressed by:

```
%match(t) {
  concString(_*,'l','l',_*) -> { ... }
}
```

Since this syntax is error prone when looking for long/complex substrings, Tom provides an abbreviated notation: 'll':

```
%match(t) {
  concString(_*,'ll',_*) -> { ... }
}
```

This notation is fully equivalent to the previous one.

6.3 String matching – continued

In the following, we consider the program:

```
public class StringMatching {
  %include { string.tom }

  public final static void main(String[] args) {
    String s = "abcabc";
    %match(s) {
      concString(_*,x,_*,x,_*)    -> { System.out.println("x = " + `x); }
      concString('a',_*,y,_*,'c') -> { System.out.println("y = " + `y); }
      concString(C1*,'abc',C2*)   -> { System.out.println("C1 = " + `C1*); }
      concString(_*,z@'bc',_*)    -> { System.out.println("z = " + `z); }
      concString(_*,L*,_*,L*,_*)  -> { if(`L*.length() > 0) {
                                         System.out.println("L = " + `L*); } }
  }
}
```

As illustrated previously, we can use variables to capture contexts. In fact, this mechanism is more general and we can use a variable anywhere to match something which is not statically known. The following pattern looks for two characters which are identical:

```
concString(_*,x,_*,x,_*) -> { System.out.println("x = " + `x); }
```

Since list matching is not unitary, there may be several results. In this case, we obtain:

```
x = a
x = b
x = c
```

The second pattern looks for a character in a string which should begin with a 'a' and end with a 'c':

```
concString('a',_*,y,_*,'c') -> { System.out.println("y = " + `y); }
```

The results are:

```
y = b
y = c
y = a
y = b
```

The third pattern look for the substring 'abc' anywhere in the string:

```
concString(C1*,'abc',C2*) -> { System.out.println("C1 = " + `C1*); }
```

When the substring is found, the prefix `C1*` is:

```
C1 =
C1 = abc
```

The last pattern illustrates the search of two identical substrings:

```
concString(_*,L*,_*,L*,_*) -> { if(‘L*.length() > 0) {
                                  System.out.println("L = " + ‘L*); } }
```

The results are:

```
L = a
L = ab
L = abc
L = b
L = bc
L = c
```

To look for a palindrome, you can use the following pattern:

```
%match(t) {
  concString(x*,y*,y*,x*) -> { /* we have found a palindrome */ }
}
```

6.4 List matching – Associative matching

As illustrated previously, Tom supports a generalized form of string matching, called *list matching*, also known as *associative matching with neutral element*. In Tom, some operators are special and do not have a fixed number of arguments. This intuitively corresponds to the idea of list where elements are stored in a given order. A list of elements may be written `(a,b,c)` or `[a,b,c]`. In Tom, it is written `f(a(),b(),c())`, where ‘`f`’ is this special operator. In some sense, ‘`f`’ is the name of the list. This allows to distinguish list of apples, from list of oranges for examples.

The definition of such operators can be done using Gom:

```
import list1.list.types.*;
public class List1 {
  %gom {
    module List
    abstract syntax
    E = a()
      | b()
      | c()
    L = f( E* )
   }
   ...
}
```

Once this signature defined, it becomes possible to define patterns and ‘ expressions. For example, the function that removes identical consecutive elements can be expressed as follows:

```
public static L removeDouble(L l) {
  %match(l) {
    f(X1*,x,x,X2*) -> {
      return removeDouble(‘f(X1*,x,X2*));
    }
  }
  return l;
}
```

This example is interesting since it expresses a complex operation in a concise way: given a list `l`, the `%match` construct looks for two identical consecutive elements (`f(X1*,x,x,X2*)` is called a non-linear pattern since `x` appears twice). If there exists such two elements, the term `f(X1*,x,X2*)` is built (an `x` has been removed), and the `removeDouble` function is called recursively. When there is no such two elements, the pattern does not match, this means that the list does not contain any consecutive identical elements. Therefore, the instruction `return l` is executed and the function returns.

Similarly, a sorting algorithm can be implemented: if a list contains two elements in the wrong order, just swap them. This can be expressed as follows:

```
public static L swapSort(L l) {
  %match(l) {
    f(X*,e1,Z*,e2,Y*) -> {
      if(‘gt(e1,e2)) {
        return ‘swapSort(f(X*,e2,Z*,e1,Y*));
      }
    }
  }
  return l;
}

private static boolean gt(E e1, E e2) {
  return e1.toString().compareTo(e2.toString()) > 0;
}
```

In this example, the order is implemented by the `gt` function, using the lexicographical ordering provided by Java.

Note: given a list `l = f(b(),b(),a(),a())`, there exists several ways to match the pattern. In this case, there are 6 possibilities:

```
1. X*=f(),         e1=b(), Z*=f(),         e2=b(), Y*=f(a(),a())
2. X*=f(),         e1=b(), Z*=f(b()),      e2=a(), Y*=f(a())
3. X*=f(),         e1=b(), Z*=f(b(),a()), e2=a(), Y*=f()
4. X*=f(b()),      e1=b(), Z*=f(),         e2=a(), Y*=f(a)
5. X*=f(b()),      e1=b(), Z*=f(a()),      e2=a(), Y*=f()
6. X*=f(b(),b()), e1=a,   Z*=f(),         e2=a(), Y*=f()
```

Assuming that `a < b`, there are only 4 solutions (2, 3, 4, and 5 since `e1` must be greater than `e2`) that can be used to apply the rule

It becomes important to remind you how a rule is applied in Tom:

1. a rule whose pattern match is selected (in our case, there is only one rule),
2. then, for each solution of the matching problem (there are 6 solutions in our case), the right part is executed (i.e. the Java code).

   Let us suppose that Tom computes the solution `1.` first (the order in which solutions are computed is not fixed and depends on the implementation). In that case, the test `if(‘gt(e1,e2))` is evaluated. Since `b()` is not greater than `b()`, the `return swapSort(...)` is not performed.

   As specified in Section 10.2.2, another solution is computed. Let us say `2.`. In that case, the test becomes true and the function `swapSort` is called recursively.
3. when there is no more solution (i.e. this means that the list is already sorted), the control is transfered to the next pattern. Since there is no more pattern in our example, the `return l` is executed, which returns the sorted list.

The following code shows how to build a list and call the function defined previously. This results in sorted lists where elements only occur once.

```
public final static void main(String[] args) {
  L l = ‘f(a(),b(),c(),a(),b(),c(),a());
```

```
  L res1 = swapSort(l);
  L res2 = removeDouble(res1);
  System.out.println(" l       = " + l);
  System.out.println("sorted l = " + res1);
  System.out.println("single l = " + res2);
}
```

Chapter 7

Language Basics – Level 3

7.1 Introduction to strategies

7.1.1 Elementary transformation

We call *strategy* an elementary transformation. Suppose that you want to transform the object `a()` into the object `b()`. You can of course use all the functionalities provided by Tom and Java. But in that case, you will certainly end in mixing the *transformation* (the piece of code that really replaces `a()` by `b()`) with the *control* (the Java part that is executed in order to perform the transformation).

The notion of strategy is a clear separation between *control* and *transformation*. In our case, we will define a strategy named `Trans1` that only describes the transformation we have in mind:

```
import main.example.types.*;
import tom.library.sl.*;

public class Main {
  %gom {
    module Example
    abstract syntax
    Term = a() | b() | f(x:Term)
  }
  %include { sl.tom }

  public final static void main(String[] args) {
    try {
      Term t1 = `a();
      Term t2 = (Term) `Trans1().visit(t1);
      System.out.println("t2 = " + t2);
    } catch(VisitFailure e) {
      System.out.println("the strategy failed");
    }
  }

  %strategy Trans1() extends Fail() {
    visit Term {
      a() -> b()
    }
  }
}
```

There exists three kinds of elementary strategy: `Fail`, which always fails, `Identity`, which always succeeds, and transformation rules of the form $l \rightarrow r$. Therefore, if we consider the elementary strategy `a` ⇒`b` (which replaces `a` by `b`), we have the following results:

```
(a -> b)[a]      = b
(a -> b)[b]      = failure
(a -> b)[f(a)]   = failure
(Identity)[a]    = a
(Identity)[b]    = b
(Identity)[f(a)] = f(a)
(Fail)[a]        = failure
```

7.1.2 Basic combinators

Composition

The sequential operator, `Sequence(S1,S2)`, applies the strategy `S1`, and then the strategy `S2`. It fails if either `S1` fails, or `S2` fails.

```
(Sequence(a -> b, b -> c))[a] = c
(Sequence(a -> b, c -> d))[a] = failure
(Sequence(b -> c, a -> b))[a] = failure
```

Choice

The choice operator, `Choice(S1,S2)`, applies the strategy `S1`. If the application `S1` fails, it applies the strategy `S2`. Therefore, `Choice(S1,S2)` fails if both `S1` and `S2` fail.

```
(Choice(a -> b, b -> c))[a]   = b
(Choice(b -> c, a -> b))[a]   = b
(Choice(b -> c, c -> d))[a]   = failure
(Choice(b -> c, Identity))[a] = a
```

Not

The strategy `Not(S)`, applies the strategy and fails when `S` succeeds. Otherwise, it succeeds and corresponds to the `Identity`.

```
(Not(a -> b))[a]   = failure
(Not(b -> c))[a]   = a
```

7.1.3 Parameterized strategies

By combining basic combinators, more complex strategies can be defined. To make the definitions generic, parameters can be used. For example, we can define the two following strategies:

- `Try(S) = Choice(S, Identity)`, which tries to apply `S`, but never fails
- `Repeat(S) = Try(Sequence(S, Repeat(S)))`, which applies recursively `S` until it fails, and then returns the last unfailing result

```
(Try(b -> c))[a]                    = a
(Repeat(a -> b))[a]                 = b
(Repeat(Choice(b -> c, a -> b)))[a] = c
(Repeat(b -> c))[a]                 = a
```

7.1.4 Traversal strategies

We consider two kinds of traversal strategy (`All(S)` and `One(S)`). The first one applies `S` to all subterms, whereas the second one applies `S` to only one subterm.

All

The application of the strategy `All(S)` to a term `t` applies `S` on each immediate subterm of `t`. The strategy `All(S)` fails if `S` fails on at least one immediate subterm.

```
(All(a -> b))[f(a)]        = f(b)
(All(a -> b))[g(a,a)]      = g(b,b)
(All(a -> b))[g(a,b)]      = failure
(All(a -> b))[a]           = a
(All(Try(a -> b)))[g(a,c)] = g(b,c)
```

Note: the application of `All(S)` to a constant *never* fails: it returns the constant itself.

One

The application of the strategy `One(S)` to a term `t` tries to apply `S` on an immediate subterm of `t`. The strategy `One(S)` succeeds if there is a subterm such that `S` can be applied. The subterms are tried from left to right.

```
(One(a -> b))[f(a)]   = f(b)
(One(a -> b))[g(a,a)] = g(b,a)
(One(a -> b))[g(b,a)] = g(b,b)
(One(a -> b))[a]      = failure
```

Note: the application of `One(S)` to a constant *always* fails: there is no subterm such that `S` can be applied.

7.1.5 High level strategies

By combining the previously mentioned constructs, it becomes possible to define well know strategies:

```
BottomUp(S)     = Sequence(All(BottomUp(S)), S)
TopDown(S)      = Sequence(S, All(TopDown(S)))
OnceBottomUp(S) = Choice(One(OnceBottomUp(S)), S)
OnceTopDown(S)  = Choice(S, One(OnceTopDown(S)))
Innermost(S)    = Repeat(OnceBottomUp(S))
Outermost(S)    = Repeat(OnceTopDown(S))
```

7.2 Strategies in practice

Let us consider again a Pico language whose syntax is a bit simpler than the one seen in section 5.5.

```
import pico2.term.types.*;
import java.util.*;
import tom.library.sl.*;

class Pico2 {
  %include { sl.tom }

  %gom {
    module Term
    imports int String

    abstract syntax
    Bool = True()
         | False()
         | Neg(b:Bool)
         | Or(b1:Bool, b2:Bool)
         | And(b1:Bool, b2:Bool)
```

```
        | Eq(e1:Expr, e2:Expr)

    Expr = Var(name:String)
         | Cst(val:int)
         | Let(name:String, e:Expr, body:Expr)
         | Seq( Expr* )
         | If(cond:Bool, e1:Expr, e2:Expr)
         | Print(e:Expr)
         | Plus(e1:Expr, e2:Expr)
  }
  ...
}
```

As an exercise, we want to write an optimization function that replaces an instruction of the form `If(Neg(b),i1,i2)` by a simpler one: `If(b,i2,i1)`. A possible implementation is:

```
  public static Expr opti(Expr expr) {
    %match(expr) {
      If(Neg(b),i1,i2) -> { return `opti(If(b,i2,i1)); }
      x -> { return `x; }
    }
    throw new RuntimeException("strange term: " + expr);
  }

  public final static void main(String[] args) {
    Expr p4 = `Let("i",Cst(0),
                  If(Neg(Eq(Var("i"),Cst(10))),
                     Seq(Print(Var("i")), Let("i",Plus(Var("i"),Cst(1)),Var("i"))),
                     Seq()));

    System.out.println("p4       = " + p4);
    System.out.println("opti(p4) = " + opti(p4));
  }
```

When executing this program, we obtain:

```
p4       = Let("i",Cst(0),If(Neg(Eq(Var("i"),Cst(10))),
           ConsSeq(Print(Var("i")),ConsSeq(Let("i",
           Plus(Var("i"),Cst(1)),Var("i")),EmptySeq)),EmptySeq))
opti(p4) = Let("i",Cst(0),If(Neg(Eq(Var("i"),Cst(10))),
           ConsSeq(Print(Var("i")),ConsSeq(Let("i",
           Plus(Var("i"),Cst(1)),Var("i")),EmptySeq)),EmptySeq))
```

This does not correspond to the expected result, simply because the `opti` function performs an optimization when the expression starts with an `If` instruction. To get the expected behavior, we have to add congruence rules that will allow to apply the rule in subterms (one rule for each constructor):

```
  public static Expr opti(Expr expr) {
    %match(expr) {
      If(Neg(b),i1,i2) -> { return `opti(If(b,i2,i1)); }
      // congruence rules
      Let(n,e1,e2)     -> { return `Let(n,opti(e1),opti(e2)); }
      Seq(head,tail*)  -> { return `Seq(opti(head),opti(tail*)); }
      If(b,i1,i2)      -> { return `If(b,opti(i1),opti(i2)); }
      Print(e)         -> { return `Print(e); }
      Plus(e1,e2)      -> { return `Plus(e1,e2); }
      x -> { return `x; }
    }
    throw new RuntimeException("strange term: " + expr);
  }
```

Since this is not very convenient, we will show how the use of strategies can simplify this task.

7.2.1 Printing constants using a strategy

Let us start with a very simple task which consists in printing all the nodes that corresponds to a constant (`Cst(_)`. To do that, we have to define an elementary strategy that is successful when it is applied on a node `Cst(_)`:

```
%strategy stratPrintCst() extends Fail() {
  visit Expr {
    Cst(x) -> { System.out.println("cst: " + ‘x); }
  }
}
```

Note: this strategy extends `Fail`. This means that its application leads to a failure when it cannot be applied. In our case, the strategy succeeds on nodes of the form `Cst(x)`, and fails on all the others. To traverse the program and print all `Cst` nodes, a `TopDown` strategy can be applied:

```
public static void printCst(Expr expr) {
  try {
    ‘TopDown(Try(stratPrintCst())).visit(expr);
  } catch (VisitFailure e) {
    System.out.println("strategy failed");
  }
}

public final static void main(String[] args) {
  ...
  System.out.println("p4 = " + p4);
  printCst(p4);
}
```

Note: the strategy given as argument of a `TopDown` should not fail. Otherwise, the `TopDown` will also fail. This is why the `stratPrint` is wrapped into a `Try`, which makes the strategy always successful. This results in:

```
p4 = Let("i",Cst(0),If(Neg(Eq(Var("i"),Cst(10))),
     ConsSeq(Print(Var("i")),ConsSeq(Let("i",
     Plus(Var("i"),Cst(1)),Var("i")),EmptySeq)),EmptySeq))
cst: 0
cst: 10
cst: 1
```

7.2.2 Combining elementary strategies

As a second exercise, we will try to write another strategy that performs the same task, but we will try to separate the strategy that looks for a constant from the strategy that prints a node. So, let us define these two strategies:

```
%strategy FindCst() extends Fail() {
  visit Expr {
    c@Cst(x) -> c
  }
}

%strategy PrintTree() extends Identity() {
  visit Expr {
    x -> { System.out.println(‘x); }
  }
}
```

Similarly to `stratPrintCst`, the strategy `FindCst` extends `Fail`. The goal of the `PrintTree` strategy is to print a node of sort `Expr`. By extending `Identity`, we specify the default behavior when the strategy is applied on a term of a different sort.

Note: we could have extended `Fail` and used `Try(PrintTree())` instead. To print the node `Cst`, we have to look for a `Cst` and print this node. This can be done by combining, using a `Sequence`, the two strategies `FindCst` and `PrintTree`:

```
public static void printCst(Expr expr) {
  try {
    `TopDown(Try(stratPrintCst())).visit(expr);
    `TopDown(Try(Sequence(FindCst(),PrintTree()))).visit(expr);
  } catch (VisitFailure e) {
    System.out.println("strategy failed");
  }
}
```

This results in:

```
cst: 0
cst: 10
cst: 1
Cst(0)
Cst(10)
Cst(1)
```

Note: in the second case, the nodes are printed using the `toString()` method generated by Gom.

7.2.3 Modifying a subterm

Here, we will try to rename all the variables from a given program: the name should be modified into `_name`.

To achieve this task, you can define a primitive strategy that performs the modification, and apply it using a strategy such as `TopDown`:

```
%strategy stratRenameVar() extends Fail() {
  visit Expr {
    Var(name) -> { return `Var("_"+name); }
  }
}

public static void optimize(Expr expr) {
  try {
    `Sequence(TopDown(Try(stratRenameVar())),PrintTree()).visit(expr);
  } catch (VisitFailure e) {
    System.out.println("strategy failed");
  }
}
```

Note: to print the resulting term, the `TopDown` application of `stratRenameVar` (wrapped by a `Try`) is combined, using a `Sequence`, with the strategy `PrintTree`. The application of `optimize` to `p4` results in:

```
Let("i",Cst(0),If(Neg(Eq(Var("_i"),Cst(10))),
  ConsSeq(Print(Var("_i")),ConsSeq(Let("i",
  Plus(Var("_i"),Cst(1)),Var("_i")),EmptySeq)),EmptySeq))
```

Suppose now that we want to print the intermediate steps: we do not want to perform all the replacements in one step, but for debugging purpose, we want to print the intermediate term after each application of the renaming rule.

The solution consists in combining the `stratRenameVar` strategy with the `PrintTree` strategy. **Note:** you can try to implement it yourself before reading the solution A first solution consists in applying `stratRenameVar` using a `OnceBottomUp` strategy, and immediately apply `PrintTree` on the resulting term. This could be implemented as follows:

```
`Repeat(Sequence(OnceBottomUp(stratRenameVar()),PrintTree())).visit(expr);
```

Unfortunately, this results in:

```
Let("i",Cst(0),If(Neg(Eq(Var("_i"),Cst(10))),...
Let("i",Cst(0),If(Neg(Eq(Var("__i"),Cst(10))),...
Let("i",Cst(0),If(Neg(Eq(Var("___i"),Cst(10))),...
Let("i",Cst(0),If(Neg(Eq(Var("____i"),Cst(10))),...
Let("i",Cst(0),If(Neg(Eq(Var("_____i"),Cst(10))),...
Let("i",Cst(0),If(Neg(Eq(Var("______i"),Cst(10))),...
Let("i",Cst(0),If(Neg(Eq(Var("_______i"),Cst(10))),...
Let("i",Cst(0),If(Neg(Eq(Var("________i"),Cst(10))),...
Let("i",Cst(0),If(Neg(Eq(Var("_________i"),Cst(10))),...
Let("i",Cst(0),If(Neg(Eq(Var("__________i"),Cst(10))),...
Let("i",Cst(0),If(Neg(Eq(Var("___________i"),Cst(10))),...
Let("i",Cst(0),If(Neg(Eq(Var("____________i"),Cst(10))),...
...
```

This is not the expected behavior! Why?

Simply because the renaming rule can be applied several times on a same variable. To fix this problem, we have to apply the renaming rule only if the considered variable has not already be renamed.

To know if a variable has been renamed, you just have to define an elementary strategy, called `RenamedVar`, that succeeds when the name of the variable starts with an underscore. This can be easily implemented using string matching capabilities:

```
%strategy RenamedVar() extends Fail() {
  visit Expr {
    v@Var(('_',name*)) -> v
  }
}
```

To finish our implementation, it is sufficient to apply `stratRenameVar` only when `RenamedVar` fails, i.e., when `Not(RenamedVar)` succeeds.

```
`Repeat(Sequence(
      OnceBottomUp(Sequence(Not(RenamedVar()),stratRenameVar())),
      PrintTree())
    ).visit(expr);
```

This results in (layouts have been added to improve readability):

```
Let("i",Cst(0),If(Neg(Eq(Var("_i"),Cst(10))),
  ConsSeq(Print(Var("i")),ConsSeq(Let("i",
  Plus(Var("i"),Cst(1)),Var("i")),EmptySeq)),EmptySeq))
Let("i",Cst(0),If(Neg(Eq(Var("_i"),Cst(10))),
  ConsSeq(Print(Var("_i")),ConsSeq(Let("i",
  Plus(Var("i"),Cst(1)),Var("i")),EmptySeq)),EmptySeq))
Let("i",Cst(0),If(Neg(Eq(Var("_i"),Cst(10))),
  ConsSeq(Print(Var("_i")),ConsSeq(Let("i",
  Plus(Var("_i"),Cst(1)),Var("i")),EmptySeq)),EmptySeq))
Let("i",Cst(0),If(Neg(Eq(Var("_i"),Cst(10))),
  ConsSeq(Print(Var("_i")),ConsSeq(Let("i",
  Plus(Var("_i"),Cst(1)),Var("_i")),EmptySeq)),EmptySeq))
```

7.2.4 Re-implementing the tiny optimizer

Now that you know how to use strategies, it should be easy to implement the tiny optimizer seen in the beginning of section 7.2.

You just have to define the transformation rule and a strategy that will apply the rule in an innermost way:

```
%strategy OptIf() extends Fail() {
  visit Expr {
    If(Neg(b),i1,i2) -> If(b,i2,i1)
  }
}

public void optimize(Expr expr) {
  try {
    `Sequence(Innermost(OptIf()),PrintTree()).visit(expr);
  } catch (VisitFailure e) {
    System.out.println("strategy failed");
  }
}
```

Applied to the program `p4`, as expected this results in:

```
Let("i",Cst(0),If(Eq(Var("i"),Cst(10)),EmptySeq,
  ConsSeq(Print(Var("i")),ConsSeq(Let("i",
  Plus(Var("i"),Cst(1)),Var("i")),EmptySeq))))
```

Note: when programming with strategies, it is no longer necessary to implement a congruence rule for each constructor of the signature.

7.3 Anti pattern-matching

Tom patterns support the use of complements, called anti-patterns. In other words, it is possible to specify what you *don't want* to match. This is done via the '`!`' symbol, according to the grammar defined in the language reference.

If we consider the Gom signature

```
import list1.list.types.*;
public class List1 {
  %gom {
    module List
    abstract syntax
    E = a()
      | b()
      | c()
      | f(x1:E, x2:E)
      | g(x3:E)
    L = List( E* )
  }
  ...
}
```

a very simple use of the anti-patterns would be

```
  ...
  %match(subject) {
    !a() -> {
      System.out.println("The subject is different from 'a'");
```

```
  }
}
...
```

The '`!`' symbols can be nested, and therefore more complicated examples can be generated:

```
...
%match(subject) {
  f(a(),!b()) -> {
    // matches an f which has x1=a() and x2!=b()
  }
  f(!a(),!b()) -> {
    // matches an f which has x1!=a() and x2!=b()
  }
  !f(a(),!b()) -> {
    // matches either something different from f(a(),_) or f(a(),b())
  }
  !f(x,x) -> {
    // matches either something different from f, or an f with x1 != x2
  }
  f(x,!x) -> {
    // matches an f which has x1 != x2
  }
  f(x,!g(x)) -> {
    // matches an f which has either x2!=g or x2=g(y) with y != x1
  }
}
...
```

The anti-patterns can be also quite useful when used with lists. Imagine that you what to search for a list that doesn't contain a specific element. Without the use of anti-patterns, you would be forced to match with a variable instead of the element you don't want, and after that to perform a test in the action part to check the contents of the variable. For the signature defined above, if we are looking for a list that doesn't contain `a()`, using the anti-patterns we would write:

```
...
%match(listSubject) {
  !List(_*,a(),_*) -> {
    System.out.println("The list doesn't contain 'a'");
  }
}
...
```

Please note that this is different from writing

```
...
%match(listSubject) {
  List(_*,!a(),_*) -> {
    // at least an element different from a()
  }
}
...
```

which would match a list that has at least one element different from `a()`.

Some more useful anti-patterns can be imagined in the case of lists:

```
...
%match(listSubject) {
```

```
    !List(_*,!a(),_*) -> {
      // matches a list that contains only 'a()'
    }
    !List(X*,X*) -> {
      // matches a non-symmetrical list
    }
    !List(_*,x,_*,x,_*) -> {
      // matches a list that has all the elements distinct
    }
    List(_*,x,_*,!x,_*) -> {
      // matches a list that has at least two elements that are distinct
    }
  }
  ...
```

7.4 Using constraints for more flexibility

Since version 2.6 of the language, a more modular syntax for `%match` and `%strategy` is proposed. Instead of having a pattern (or several for more subjects) as the left-hand side of rules in a `%match` or `%strategy`, now more complex conditions can be used.

Let's consider the following class that includes a Gom signature:

```
import constraints.example.types.*
public class Constraints {
  %gom {
    module Example
    abstract syntax
    E = a()
      | b()
      | c()
      | f(x1:E, x2:E)
      | g(x3:E)

    L = List( E* )
  }
  ...
}
```

Let's now suppose that we have the following `%match` construct:

```
  ...
  %match(subject) {
    f(x,y) -> {
        boolean flag = false;
        %match(y){
          g(a())     -> { flag = true; }
          f(a(),b()) -> { flag = true; }
        }
        if (flag) { /* some action */ }
      }
      g(_) -> { System.out.println("a g(_)"); }
  }
  ...
```

This is a very basic example where we want to check if the subject is an `f` with the second sub-term either `g(a())` or `f(a(),b())`. If it is the case, we want to perform an action.

Using the new syntax of the `%match` construct (detailed in the language reference), we could write the following equivalent code:

```
...
%match(subject) {
  f(x,y) && ( g(a()) << y || f(a(),b()) << y ) -> { /* some action */ }
  g(_) -> { System.out.println("g()"); }
}
...
```

The `%match` construct can be also used without any parameters. The following three constructs are all equivalent:

```
...
%match(subject1, subject2) {
  p1,p2 -> { /* action 1 */ }
  p3,p4 -> { /* action 2 */ }
}
...
```

```
...
%match(subject1) {
  p1 && p2 << subject2 -> { /* action 1 */ }
  p3 && p4 << subject2 -> { /* action 2 */ }
}
...
```

```
...
%match {
  p1 << subject1 && p2 << subject2 -> { /* action 1 */ }
  p3 << subject1 && p4 << subject2 -> { /* action 2 */ }
}
...
```

A big advantage of the this approach compared to the classical one is its flexibility. The right-hand side of a match constraint can be a term built on variables coming from the left-hand sides of other constraints, as we saw in the first example of this section. A more advanced example could verify for instance that a list only contains two occurrences of an object:

```
...
%match(sList) {
  List(X*,a(),Y*,a(),Z*) && !List(_*,a(),_*) << List(X*,Y*,Z*) -> {
    System.out.println("Only two objects a()");
  }
}
...
```

In the above example, the first pattern checks that the subject contains two objects `a()`, and the second constraint verifies that the rest of the list doesn't contain any `a()`.

Besides match constraints introduced with the symbol `<<`, we ca also have *boolean* constraints by using the following operators: `>`, `>=`, `<`, `<=`, `==` and `!=`. These can be used between any terms, and are trivially translated into host code (this means that the constraint `term1 == term2` will correspond exactly to an `if (term1 == term2) ...` in the generated code). A simple example is the following one, which prints all the elements in a list of integers that are bigger than `5`:

```
...
%gom {
  module Example
  imports int
  abstract syntax
  Lst = intList( int* )
```

```
}
Lst sList = `intList(6,7,4,5,3,2,8,9);
%match(sList) {
  intList(_*,x,_*) && x > 5 -> { System.out.println(`x);
  }
}
...
```

Note: As inside a `%strategy` we have in fact the body of a `%match`, we can of course use the constraints in the left-hand side of the rules exactly as we do in the case of `%match`. For instance, we may write:

```
...
%strategy MyStrat() extends Identity() {
  visit E {
    f(x,y) && ( g(a()) << y || f(a(),b()) << y ) -> { /* some action */ }
  }
}
...
```

This is particulary useful even for simple conjunctions, as in a `%strategy` we cannot have multiple subjects like in `%match`.

Note: When using a disjunction, the action is executed for each case that renders the disjunction valid (given of course that no `return` or `break` is used). For instance, the following code prints the messages `here x=a()` and `here x=b()`:

```
...
%match {
   x << a() || x << b() -> { System.out.println("here x=" + `x); }
}
...
```

Chapter 8

Advanced features (*)

8.1 Hand-written mappings

Up to now, we have considered examples where the implementation of data-types is either predefined (Xml case), or generated by a tool (Gom case). One interesting contribution of Tom is to be customizable. By defining a mapping between the signature formalism (`%typeterm`, `%op`, *etc.*) and the concrete implementation, it becomes possible to perform pattern matching against any data-structure.

8.1.1 Defining a simple mapping

In this section, we consider that we have a Java library for representing tree based data structures. On another side, to be able to use Tom, we consider the following abstract data-type:

```
%typeterm Nat
%op Nat zero()
%op Nat suc(Nat)
```

By doing so, we have defined a sort (`Nat`), and two operators (`zero` and `suc`). When defining a mapping, the goal consists in explaining to Tom how the considered abstract data-type is implemented, and how a term (over this signature) can be de-constructed.

For expository reasons, the ATerm library is the Java library used to implement terms. However, any other tree/term based library could have been used instead.

In order to define a correct mapping, we have to describe how the algebraic sort (`Nat` in our example) is implemented (by the `ATermAppl` class). This is done via the `implement` construct:

```
%typeterm Nat {
  implement { ATermAppl }
}
```

The second part of the mapping definition consists in defining how the symbols (`zero` and `suc`) are represented in memory. This is done via the `is_fsym` construct:

```
%op Nat zero() {
  is_fsym(t) { t.getName().equals("zero") }
}

%op Nat suc(pred:Nat) {
  is_fsym(t)       { t.getName().equals("suc") }
  get_slot(pred,t) { (ATermAppl)t.getArgument(0) }
}
```

In addition, `get_slot` describes how to retrieve a subterm of a term.

Given a term built over the ATerm library, it becomes possible to perform pattern matching as previously explained.

8.1.2 Using backquote constructs

When using the backquote construct (`‘suc(suc(zero))` for example), Tom has to know how to build a term in memory. For this purpose, we consider an extension of the signature definition formalism: the `make` construct.

```
%op Nat zero() {
  is_fsym(t) { t.getName().equals("zero") }
  make       { SingletonFactory.getInstance().makeAppl(
                 SingletonFactory.getInstance().makeAFun("zero",0,false)) }
}

%op Nat suc(pred:Nat) {
  is_fsym(t)       { t.getName().equals("suc") }
  get_slot(pred,t) { (ATermAppl)t.getArgument(0) }
  make(t)          { SingletonFactory.getInstance().makeAppl(
                       SingletonFactory.getInstance().makeAFun("suc",1,false),t) }
}
```

The `makeAFun` function has three arguments: the function name, the number of arguments and a boolean that indicates if the quotes are included in the function name or not.

Given this mapping, Tom can be used as previously: the following function implements the addition of two Peano integers:

```
public ATermAppl plus(ATermAppl t1, ATermAppl t2) {
  %match(t2) {
    zero() -> { return t1; }
    suc(y) -> { return ‘suc(plus(t1,y)); }
  }
  return null;
}
```

8.1.3 Advanced examples

Let us suppose that we have a Java class `Person` with two getters (`getFirstname` and `getLastname`). In order to illustrate the signature definition formalism, we try to redefine (without using Gom) the abstract data type for the sort `Person`.

The first thing to do consists in defining the Tom sort `Person`:

```
%typeterm Person {
  implement { Person }
}
```

To avoid any confusion, we use the same name twice: the Tom sort `Person` is implemented by the Java class `Person`. When declaring an operator, we defined the behavior as shown in the previous example:

```
%op Person person(firstname:String, lastname:String) {
  is_fsym(t) { t instanceof Person }
  get_slot(firstname,t) { t.getFirstname() }
  get_slot(lastname,t) { t.getLastname() }
  make(t0, t1) {  new Person(t0, t1) }
}
```

In this example, we illustrate another possibility offered by Tom: being able to know whether a term is rooted by a symbol without explicitly representing this symbol. The `is_fsym(t)` construct should return `true` when the term `t` is rooted by the algebraic operator we are currently defining. In this example, we say that the term `t` is rooted by the symbol `person` when the object `t` is implemented by an instance of the class `Person`. By doing so, we do not explicitly represent the symbol `person`, even if it could have been done via the reflective capabilities of Java (by using `Person.getClass()` for example).

8.1.4 Using list-matching

In this section, we show how to describe a mapping for associative operators.

```
%typeterm TomList {
  implement { ArrayList }
  equals(l1,l2)      { l1.equals(l2) }
}
```

Assuming that the sort `Element` is already defined, we can use the `%oparray` construct to define an associative operator. We also have to explain to Tom how to compute the size of a list, and how to access a given element. This is done via `get_size` and `get_element` constructs:

```
%oparray TomList conc( Element* ) {
  is_fsym(t)       { t instanceof ArrayList }
  get_element(l,n) { (ATermAppl)l.get(n) }
  get_size(l)      { l.size() }
  make_empty(n)    { myEmpty(n) }
  make_append(e,l) { myAdd(e,(ArrayList)l) }
}
```

This construct is similar to `%op` except that additional information have to be given: how to build an empty list (`make_empty`), and how to add an element to a given list (`make_append`). The auxiliary `Java` functions are defined as follows:

```
private static ArrayList myAdd(Object e,ArrayList l) {
  l.add(e);
  return l;
}

private static ArrayList myEmpty(int n) {
  ArrayList res = new ArrayList(n);
  return res;
}
```

Usually, we use an associative operator to represent (in a abstract way) a list data structure. There are many ways to implement a list, but the two most well-known are the use of array based list, and the use of linked-list. The previously described mapping shows how to map an abstract list to an array based implementation.

Tom offers another similar construct `%oplist` to map an associative operator to a linked-list based implementation. When using the ATerm library for example, a possible implementation could be:

```
%typeterm TomTerm {
  implement { aterm.ATermAppl }
  equals(t1, t2)     { t1==t2 }
}
%typeterm TomList {
  implement { ATermList }
  equals(l1,l2) { l1==l2 }
}

%oplist TomList conc( TomTerm* ) {
  is_fsym(t) { t instanceof aterm.ATermList }
  make_empty()  { aterm.pure.SingletonFactory.getInstance().makeList() }
  make_insert(e,l) { l.insert(e) }
  get_head(l)   { (aterm.ATermAppl)l.getFirst() }
  get_tail(l)   { l.getNext() }
  is_empty(l)   { l.isEmpty() }
}
```

Chapter 9

XML

Even if this section mostly deals with Xml features, every explained technique can be used with other data-structures as well.

Note: this section is not very up-to-date. In particular, the explanations about `genericTraversal` functions should be replaced by some strategies.

9.1 Manipulating Xml documents

This example is inspired from a practical study. It involves a simple modeling of the Platform for Privacy Preferences Project (P3P), developed by the World Wide Web Consortium, which is emerging as an industry standard providing a simple, automated way for users to gain more control over the use of personal information on Web sites they visit.

Given a client and a server, the problem consists in verifying that the client's policy is compliant with the server's policy. Both policies preferences are expressed in APPEL (A P3P Preference Exchange Language) and written in Xml. The server's policy is the following file `server.xml`:

```
<POLICIES xmlns="http://www.w3.org/2002/01/P3Pv1">
  <POLICY name="mypolicy" discuri="http://www.ibm.com/privacy"
          opturi="http://www.ibm.com/privacy" xml:lang="en">
    <STATEMENT>
      <RECIPIENT> <delivery/> </RECIPIENT>
      <PURPOSE> <contact/> </PURPOSE>
      <DATA-GROUP>
        <DATA ref="#dynamic.clickstream"/>
        <DATA ref="#dynamic.http"/>
        <DATA ref="#dynamic.clientevents"/>
        <DATA ref="#user.home-info.postal.country"/>
        <DATA ref="#dynamic.cookies"> <CATEGORIES> <content/> </CATEGORIES> </DATA>
      </DATA-GROUP>
    </STATEMENT>
  </POLICY>
</POLICIES>
```

The client's policy is the following file `client.xml`:

```
<RULESET appel="http://www.w3.org/2002/04/APPELv1"
         p3p="http://www.w3.org/2000/12/P3Pv1"
         crtdby="W3C" crtdon="2001-02-19T16:21:21+01:00">
  ...
  <RULE behavior="limited1" prompt="yes">
    <POLICY>
      <STATEMENT>
        <PURPOSE connective="and-exact"> <current/> </PURPOSE>
```

```
        <RECIPIENT connective="or">
          <other-recipient/>
          <public/>
          <unrelated/>
        </RECIPIENT>
      </STATEMENT>
    </POLICY>
  </RULE>
  ...
  <RULE behavior="request" prompt="yes">
    <POLICY>
      <STATEMENT>
        <DATA-GROUP>
          <DATA ref="#dynamic.clientevents"> </DATA>
          <DATA ref="#dynamic.clickstream"/>
        </DATA-GROUP>
      </STATEMENT>
    </POLICY>
  </RULE>
  ...
</RULESET>
```

For expository reasons, we consider only a sub-problem in which we say that a client's policy is compatible with the server's policy if all `ref` attributes from a <DATA></DATA> node also appear on the server side. In the considered examples, the policies are compatible because

```
<DATA-GROUP>
  <DATA ref="#dynamic.clientevents"> </DATA>
  <DATA ref="#dynamic.clickstream"/>
</DATA-GROUP>
```

is included in:

```
<DATA-GROUP>
  <DATA ref="#dynamic.clickstream"/>
  <DATA ref="#dynamic.http"/>
  <DATA ref="#dynamic.clientevents"/>
  <DATA ref="#user.home-info.postal.country"/>
  <DATA ref="#dynamic.cookies"> <CATEGORIES> <content/> </CATEGORIES> </DATA>
</DATA-GROUP>
```

The problem consists in implementing such a verification tool in Tom and Java.

9.1.1 Loading Xml documents

The first part of the program declares imports, and defines the `main` and the `run` methods.

```
import tom.library.xml.*;
import tom.library.adt.tnode.*;
import tom.library.adt.tnode.types.*;
import aterm.*;
import java.util.*;

public class Evaluator {

  %include{ adt/tnode/TNode.tom }

  private XmlTools xtools;
```

```
  public static void main (String args[]) {
    xtools = new XmlTools();
    TNode server = (TNode)xtools.convertXMLToATerm("server.xml");
    TNode client = (TNode)xtools.convertXMLToATerm("client.xml");
    boolean compatible = compareDataGroup(getDataGroup(server.getDocElem()),
                                          getDataGroup(client.getDocElem()));
    System.out.println("result = " + compatible);
  }
  ...
}
```

As explained in Part III (Tom language description), to each XML document corresponds a DOM (Document Object Model) representation. In Tom, we have defined a mapping from DOM sorts to abstract algebraic sorts: `TNode` and `TNodeList`, which correspond respectively to `Node` and `NodeList`, defined by the Java DOM implementation.

This mapping has to be initialized in the following way:

- the import of `tom.library.adt.tnode.*` and `tom.library.adt.tnode.types.*` defines the sorts `TNode` and `TNodeList` and allows us to build objects over these two sorts.
- the `%include{ TNode.tom }` Tom construct is similar to the `#include` C preprocessor construct. In this case, it imports the definition of Tom algebraic constructors needed to manipulate XML documents.

In complement to Tom, we provide a runtime library which contains several methods to manipulate XML documents. In particular, we provide the `XmlTools` class (defined in the `tom.library.xml.*` package).

The `run` method takes two filenames as arguments, reads the associated files and convert their XML content into `TNode` terms (using the `convertXMLToATerm` function).

The `getDataGroup` function is used to retrieve a <DATA></DATA> node in the considered XML document. Note that `getDocElem` is first applied to XML documents in order to consider subterms of the `DocumentNode` element. Then, the `compareDataGroup` function is used to check that the client's policy is compatible with the server's policy. The content of these functions is detailed in the next sections.

9.1.2 Retrieving information

Given an XML subtree, the problem consists in extracting a <DATA-GROUP></DATA-GROUP> node. For expository reasons, we first consider that such a <DATA-GROUP></DATA-GROUP> node can only appear at two different specific places: one for the client's definition and one for the server's definition.

Thus, in the Tom program we naturally consider two cases:

```
  private static TNode getDataGroup(TNode doc) {
    %match(doc) {
      <POLICIES>
         <POLICY>
           <STATEMENT>
             datagroup@<DATA-GROUP></DATA-GROUP>
           </STATEMENT>
         </POLICY>
      </POLICIES> -> { return datagroup; }

      <RULESET>
        <RULE>
          <POLICY>
            <STATEMENT>
              datagroup@<DATA-GROUP></DATA-GROUP>
             </STATEMENT>
          </POLICY>
```

```
        </RULE>
      </RULESET> -> { return datagroup; }
    }

    return `xml(<DATA-GROUP/>);
  }
```

The first pattern means that a <DATA-GROUP></DATA-GROUP> node has to be found under a <STATEMENT></STATEMENT> node, which should be under a <POLICY></POLICY> node, which should be under a <POLICIES></POLICIES> node. Once such a pattern is found, the mechanism allows us to give a name (`datagroup`) to this subterm and reuse it in the action part: `return datagroup;`.

The Xml notation implicitly extends the given patterns by adding context variables. Thus, the <DATA-GROUP></DATA-GROUP> pattern means that a subterm those head symbol is <DATA-GROUP></DATA-GROUP> is searched. But this subterm can contain attributes and children even if it is not explicitly defined by the notation. To make the definition of patterns more precise, the user can use the explicit notation and define the following pattern: <DATA-GROUP (_*)>(_*)</DATA-GROUP>. A more detailed explanation can be found in Part III (Tom language description).

9.1.3 Comparing two Xml subtrees

Given two <DATA-GROUP></DATA-GROUP> nodes, the problem consists in checking that all <DATA></DATA> nodes from the first tree also appear in the second one. This can be easily implemented by the following couple of functions:

```
private static boolean compareDataGroup(TNode server, TNode client) {
  boolean res = true;
  %match(client) {
    <DATA-GROUP><DATA ref=reftext></DATA></DATA-GROUP>
    -> { res = res && appearsIn(reftext,server); }
  }
  return res;
}
```

Given a <DATA-GROUP></DATA-GROUP> tree, we look for a <DATA></DATA> subtree which contains an attribute named `ref`. When such an attribute exists, its content (a string) is stored into the Java `reftext` variable. The `appearsIn` function is then used to check that the attribute also appears on the server side.

```
private static boolean appearsIn(String refclient, TNode server) {
  %match(server) {
    <DATA-GROUP><DATA ref=reftext></DATA></DATA-GROUP>
    -> {
       if(reftext.equals(refclient)) {
         return true;
       }
     }
  }
  return false;
}
```

This piece of code is interesting because it introduces what we call "conditional rules". Given the string `refclient` we look for a <DATA></DATA> subtree containing a `ref` attribute with exactly the same string. Since it is not possible to use an instantiated variable in a pattern (something like <DATA ref=refclient>...</DATA>, we have to introduce a fresh variable `reftext` and check in a condition that this variable is equal to `refclient`. This is done via a Java condition (the `if` clause): the action part (`return true;`) is executed only when the condition is satisfied, and clearly it will end the method. If the condition is not satisfied, then the next <DATA></DATA> subtree is searched. It is exactly the case of a switch statement, when the action part is not exited by a `return`, `break` or `goto`, and the control flow is transferred to the next matching solution or the next matching pattern.

If no such subtree exists, this means that the two policies are not compatible and `false` is returned.

9.1.4 Retrieving information using traversal functions

The Tom runtime library provides a set of generic functions in order to perform various kinds of traversal over a term. This is useful when searching a pattern somewhere in a term, at any position. As the XML documents are seen by Tom as terms, the different traversals on terms are also valid when dealing with XML.

In the current example, the `getDataGroup` functions looks for a `<DATA-GROUP></DATA-GROUP>` node. Instead of statically specifying the path (`POLICIES, POLICY, STATEMENT, DATA-GROUP` and `RULESET, RULE, POLICY, STATEMENT, DATA-GROUP`) we could have used the generic traversal mechanism provided by the package `tom.library.traversal.*`.

```
private static GenericTraversal traversal = new GenericTraversal();
```

In the following, we generalize the previous problem by considering that we can have more than one appearance of the `<DATA-GROUP></DATA-GROUP>` node per XML document.

We further expose the use of the generic traversal mechanism. The `collectDatagroup` method creates an inner class `Collect1` with one method, `apply`, and then it calls the `genericCollect` method of the traversal object created previously with an object of this inner class as a parameter.

```
protected static void collectDatagroup(final Collection collection, TNode subject) {
  Collect1 collect = new Collect1() {
      public boolean apply(ATerm t) {
        if(t instanceof TNode) {
          %match(t) {
            <DATA-GROUP> </DATA-GROUP> -> {
               collection.add(t);
               return false;
             }
          }
        }
        return true;
      } // end apply
    }; // end new

  traversal.genericCollect(subject, collect);
}
```

Let us now analyze the inner class: firstly, it extends the class `Collect1`, where `1` stands for the number of arguments of the `apply` method, and secondly it implements the method `apply`. The method call `traversal.genericCollect` will call this method for all subtrees of the `subject` term. Since `subject` may contain subterms of different sorts (integers or strings for example), the `instanceof` construct is used as a first filter to select only the subterms which correspond to XML nodes. When such a subterm is rooted by a `<DATA-GROUP></DATA-GROUP>`, the subterm is added to the collection (by a side-effect). The `return false;` statement indicates that it is no longer necessary to traverse the considered term (in our example, a `<DATA-GROUP></DATA-GROUP>` node cannot be found inside a `<DATA-GROUP></DATA-GROUP>` itself). Respectively, the `return true;` statement indicates that the `apply` function should be recursively applied to the current term in order to continue the traversal.

Given a collection, the `getDataGroup` method uses an iterator to select a `<DATA-GROUP></DATA-GROUP>` node.

```
private static TNode getDataGroup(TNode doc) {
  HashSet c = new HashSet();
  collectDatagroup(c,doc);
  Iterator it = c.iterator();
  while(it.hasNext()) {
    TNode datagroup = (TNode)it.next();
```

```
      return datagroup;
    }

    return `xml(<DATA-GROUP/>);
  }
```

9.2 Building and sorting Xml/DOM documents

In this section, we consider a DOM mapping for Xml documents. This means that Xml documents are still considered as algebraic terms (built over `TNode` and `TNodeList`), but their internal representation is backed by the W3C DOM library.

In the following, we consider a small data-base represented by an Xml document `person.xml`:

```
<Persons>
  <Person Age="30"> <FirstName> Paul   </FirstName> </Person>
  <Person Age="28"> <FirstName> Mark   </FirstName> </Person>
  <Person Age="21"> <FirstName> Jurgen </FirstName> </Person>
  <Person Age="21"> <FirstName> Julien </FirstName> </Person>
  <Person Age="24"> <FirstName> Pierre-Etienne </FirstName> </Person>
</Persons>
```

The problem consists in sorting this document according to different criteria (age or first-name for example).

9.2.1 Loading Xml documents

The first part of the program declares imports, and defines the `main` method.

```
import org.w3c.dom.*;
import javax.xml.parsers.*;
import javax.xml.transform.*;
import javax.xml.transform.dom.DOMSource;
import javax.xml.transform.stream.StreamResult;
import java.io.File;

public class PersonSort1 {
  private static Document dom;
  %include{ dom.tom }

  public static void main (String args[]) {
    try {
      dom = DocumentBuilderFactory.newInstance()
        .newDocumentBuilder().parse("person.xml");
      Element e = dom.getDocumentElement();
      dom.replaceChild(sort(e),e);

      Transformer transform = TransformerFactory.newInstance().newTransformer();
      StreamResult result = new StreamResult(new File("Sorted.xml"));
      transform.transform(new DOMSource(dom), result);
    } catch (Exception e) {
      e.printStackTrace();
    }
  }

  ...
}
```

The mapping has to be initialized in the following ways:

- the import of `org.w3c.dom.*` and `javax.xml.*` packages in order to use the DOM library.
- the `%include{ dom.tom }` construct imports the definition of Tom algebraic constructors needed to manipulate DOM objects.
- the `dom` variable has to be instantiated. This variable corresponds to the notion of Document in the DOM terminology.

9.2.2 Comparing two nodes

In order to implement a sorting algorithm, we need to know how to compare two elements.

The following function takes two XML documents in argument and compares their attribute `Age`, using the string comparison operator `compareTo`.

```
private static int compare(Node t1, Node t2) {
  %match(t1, t2) {
    <Person Age=a1></Person>, <Person Age=a2></Person> -> {
      return `a1.compareTo(`a2);
    }
  }
  return 0;
}
```

In this example, it is interesting to note that an XML node is seen as an associative operator. This feature, combined with the implicit notation, is such that `<Person Age=a1></Person>` will match any XML node headed by `Person` which contains the attribute `Age`. This XML node may contain several sub-nodes, but they will not be stored in any variable.

9.2.3 Sorting a list of nodes

In this section we use a swap sort algorithm which consists in finding two elements that are not in the correct order. Once they are found, they are swapped before calling the algorithm recursively. When no two such elements exist, this means that the list is sorted.

```
private static Node sort(Node subject) {
  %match(subject) {
   <Persons>(X1*,p1,X2*,p2,X3*)</Persons> -> {
      if(compare(`p1,`p2) > 0) {
        return sort(`xml(dom,<Persons>X1* p2 X2* p1 X3*</Persons>));
      }
    }
  }
  return subject;
}
```

The pattern `<Persons>(X1*,p1,X2*,p2,X3*)</Persons>` looks for two elements `p1` and `p2` and stores the remaining contexts in `X1*`, `X2*`, and `X3*`. In order to give a name to contexts (and then retrieve them to build a new list), the pattern is written in explicit notation. This notation prevents Tom to add extra variables. Otherwise, the expanded form of `<Persons>X1* p1 X2* p2 X3*</Persons>` (written in explicit notation) would have been `<Persons>(_*,X1*,_*,p1,_*,X2*,_*,p2,_*,X3*,_*)</Persons>`.

Note that the action part is guarded by a condition (`if(compare(p1,p2) > 0)`). This means that `return sort(...)` is executed only when two bad-ordered elements are found. When `p1` and `p2` are correctly ordered, the matching procedure continues and extracts another couple `p1` and `p2`. As mentioned in Part III, when Tom cannot find two elements `p1` and `p2` such that the condition is satisfied (the list is sorted), the `return sort(...)` statement is not executed and the control flow is transferred to the following statement: `return subject;`

As mentioned previously, when two elements have to be swapped, a new list is built. This done via the ‘‘’ (backquote) construct. This construct, used before to retrieve instantiated variables, can also be use to build a new term. In order to build an XML document, the `xml(...)` function has to be used. The number of parameters depends on the XML mapping which is used. In our case, when manipulating DOM objects, a new subtree is built is the context of a main document. This extra-parameter is given in the first argument of the `xml` function. Thus, `‘xml(dom,<Persons>...<Persons>)` builds a new `<Person></Person>` node, as a child of the `dom` document. When using the `TNode.tom` mapping, a library based on Gom is used. In this case, it is no longer necessary (and even not correct) to use this extra argument.

9.2.4 Sorting by side effect

In the previous section, we considered a sorting algorithm expressed in a pure functional programming style: when two elements have to be swapped, a new list is built and returned.

In the following example, we exploit OO-style of the DOM library and perform a swap in place: the list is updated by swapping two elements (with side effect):

```
private static void sort(Node subject) {
  %match(subject) {
    r @ <_>p1@<_ Age=a1></_> p2@<_ Age=a2></_></_> -> {
      if(‘a1.compareTo(‘a2) > 0) {
        ‘r.replaceChild(‘p2.cloneNode(true),‘p1);
        ‘r.replaceChild(‘p1,‘p2);
        ‘sort(r);
        return;
      }
    }
  }
}
```

In this example, we use the notion of anonymous XML node (`<_>...</_>`) which allows to describe more generic algorithms.

Part III

Language

Chapter 10

Tom

10.1 Notations

The syntax of the language is given in BNF-like notation. Terminal symbols are set in typewriter font (‘`like this`’). Non-terminal symbols are set in italic font (*like that*). Square brackets [...] denote optional components. Parentheses with a trailing star sign (...)* denotes zero, one or several repetitions of the enclosed components. Parentheses with a trailing plus sign (...)+ denote one or several repetitions of the enclosed components. Parentheses (...) denote grouping.

10.1.1 Lexical conventions

Identifier	::=	*Letter* (*Letter* | *Digit* | ‘_’ | ‘-’)*
Integer	::=	(*Digit*)+
Double	::=	(*Digit*)+ [‘`.`’] (*Digit*)* | ‘`.`’ (*Digit*)+
String	::=	‘`"`’ (*Letter* | (‘\’ (‘`n`’ | ‘`t`’ | ‘`b`’ | ‘`r`’ | ‘`f`’ | ‘\’ | ‘`'`’ | ‘`"`’)))* ‘`"`’
Letter	::=	‘`A`’ ... ‘`Z`’ | ‘`a`’ ... ‘`z`’
Digit	::=	‘`0`’ ... ‘`9`’
Char	::=	‘`'`’ (*Letter* |*Digit*) ‘`'`’

10.1.2 Names

SubjectName	::=	*Identifier*
Type	::=	*Identifier*
SlotName	::=	*Identifier*
HeadSymbol	::=	*Identifier*
	|	*Integer*
	|	*Double*
	|	*String*
	|	*Char*
VariableName	::=	*Identifier*
AnnotedName	::=	*Identifier*
LabelName	::=	*Identifier*
FileName	::=	*Identifier*
AttributeName	::=	*Identifier*
XMLName	::=	*Identifier*
Name	::=	*Identifier*

10.2 Tom constructs

A Tom program is a host language program (namely *C*, *Java*, or *Caml*) extended by several new constructs such as `%match`, `%strategy`, `%include`, `%gom`, or `backquote`. Tom is a multi-language compiler, and therefore its syntax depends on the host language syntax. But for simplicity, we only present the syntax of its constructs and explain how they can be integrated into the host language.

Using Java as a *host-language*, the following Tom program is correct:

```
public class HelloWorld {
  %include { string.tom }

  public final static void main(String[] args) {
    String who = "World";
    %match(who) {
      "World" -> { System.out.println("Hello " + who); }
      _       -> { System.out.println("Don't panic"); }
    }
  }
}
```

10.2.1 Tom program

A Tom program is a list of blocks, where each block is either a Tom construct, or a sequence of characters (host language code). When compiling a Tom program, the Tom constructs are transformed into host language code, and the result is a valid host language program. For instance, in the previous example, `%include` and `%match` constructs are replaced by function definitions and Java instructions, making the resulting program a correct Java program.

Syntax of a Tom program:

```
Tom       ::=  BlockList
BlockList ::=
              (   MatchConstruct
              |   StrategyConstruct
              |   BackQuoteTerm
              |   IncludeConstruct
              |   GomConstruct
              |   TypeTerm
              |   Operator
              |   OperatorList
              |   OperatorArray
              |   '{' BlockList '}'
              )*
```

- MatchConstruct is translated into a list of instructions. This construct may appear anywhere a list of instructions is valid in the host language.

- StrategyConstruct is translated into a class definition. Since it is translated into a class, this construct is valid only for Java.

- BackQuoteTerm is translated into a function call.

- IncludeConstruct is replaced by the content of the file referenced by the construct. Tom looks for include files in: `./packageName/`, `$TOM_HOME/share/jtom/` and `<path>`, where `<path>` is specified by option: `--import <path>`. If the file contains some Tom constructs, they are expanded.

- GomConstruct allows to define a Gom grammar. This construct is replaced by the content of the generated mapping. See Section 10.3.4 and Chapter 11 for more details.

- TypeTerm, as well as Operator, OperatorList, and OperatorArray are replaced by some functions definitions.

10.2.2 Match construct

The `%match` construct (MatchConstruct) is one of the main contributions of Tom. This construct can be seen as an extension of the SwitchCase construct in C or Java, except that patterns are no longer restricted to constants (chars or integers). Given an object (the subject) and a list of patterns, our goal is to find the first pattern that *matches* the subjects (i.e. that has a *compatible shape*). More formally, a pattern is a term built over variables and constructors. The latter ones describe the *shape* of the pattern, whereas the variables are *holes* that can be instantiated to capture a value. When we consider the term $f(a(), g(b()))$, it has to be viewed as a tree based data-structure with f as a root and $a()$ the first child. Similarly, $b()$ is the unique child of g, which is the second child of the root f . We say that the pattern $f(x, y)$ matches this term (called subject), because we can give values to x and y such that the pattern and the subject become equal: we just have to assign $a()$ to x and $g(b())$ to y. Finding this assignment is called matching and instantiating. This is exactly what Tom is supposed to do. A pattern may of course contain subterms. Therefore, $f(x, g(b()))$ or $f(a(), g(y))$ are valid patterns which match against the subject.

Assuming that `s` is a Java variable, referencing a term (the tree based object $f(a(), g(b()))$ for example), the following Tom construct is valid:

```
%match(s) {
  f(a(),g(y)) -> { /* action 1: code that uses y */ }
  f(x,g(b())) -> { /* action 2: code that uses x */ }
  f(x,y)      -> { /* action 3: code that uses x and y */ }
}
```

The `%match` construct is defined as follows:

MatchConstruct	::=	'`%match`' '(' MatchArguments ')' '{' (PatternAction)* '}'
	|	'`%match`' '{' (ConstraintAction)* '}'
MatchArguments	::=	[Type] Term (',' [Type] Term)*
PatternAction	::=	[LabelName':'] PatternList '->' '{' BlockList '}'
PatternList	::=	Pattern(',' Pattern)* [('&&' |'||') Constraint]
ConstraintAction	::=	Constraint '->' '{' BlockList '}'
Constraint	::=	Pattern '<<' [Type] Term
	|	Constraint '&&' Constraint
	|	Constraint '||' Constraint
	|	'(' Constraint ')'
	|	Term Operator Term
Operator	::=	'>' |'>=' |'<' |'<=' |'==' |'!='

A MatchConstruct is composed of two parts:

- a list of *subjects* (the arguments of `%match`),
- a list of PatternAction: this is a list of pairs (pattern,action), where an action is a set of host language instructions which is executed each time a pattern matches the subjects.

Since version 2.6 of the language, an additional syntax, based on *constraints*, is proposed. In this case, the MatchConstruct can be simply seen as a list of pairs (constraint,action) corresponding to ConstraintAction from the above syntax. For instance, the example we presented before can now be written:

```
%match {
  f(a(),g(y)) << s -> { /* action 1 : code that uses y */ }
  f(x,g(b())) << s -> { /* action 2 : code that uses x */ }
  f(x,y) << s      -> { /* action 3 : code that uses x and y */ }
}
```

The two versions are semantically equivalent. The expression `p << s` denotes a match constraint between the pattern `p` and the subject `s`. The advantage of this new syntax is the modularity that it offers. For instance, multiple constraints can be combined with the boolean connectors '`&&`' and '`||`', leading to a greater expressivity, sometimes closed to the one offered by regular expressions.

The two syntaxes are compatible. For instance the following construct is valid:

```
%match(s) {
  f(a(),g(y)) && ( y << a() || y << b() ) -> { /* action 1 : code that uses y */ }
  f(x,g(b())) -> { /* action 2 : code that uses x */ }
}
```

Note: The right-hand sides of the constraints may contain variables that can be found in the left-hand side of other constraints. For instance we may write:

```
%match(s) {
  f(a(),g(y)) && ( g(z) << y || f(z,_) << y ) -> { /* action 1 : code that uses y and z */ }
  f(x,g(b())) && f(y,a()) << someHostFunction(x) -> { /* action 2 : code that uses x and y */ }
}
```

where `someHostFunction` can be an arbitrary function from the host language.
Note: Constraints built using an operator are trivially translated into host code. For instance, the constraint `x == g(a()) ...` is translated into the Java code

```
if (x == g(a())) {
  ...
}
```

For expository reasons, we consider that a `%match` construct is evaluated in the following way:

- given a list of subjects (they correspond to objects only composed of constructors, therefore without variables, usually called ground terms), the execution control is transferred to the first PatternAction whose patterns match the list of ground terms (in the case constraints are used, the execution control is transferred to the first ConstraintAction whose Constraint is evaluated to true).

  Note: since version 2.4, a subject is no longer restricted to a host language variable. A Tom term built upon variables, constructors and host-language functions can be used. Note also that the sort (the type of the subjects) is now optional — it is inferred from the type of the patterns.

- given such a PatternAction (respectively ConstraintAction), its variables are instantiated and the associated semantic action is executed. The instantiated variables are bound in the underlying host-language, and thus can be used in the action part.

- if the execution control is transferred outside the `%match` instruction (by a `goto`, `break` or `return` for example), the matching process is finished. Otherwise, the execution control is transferred to the next PatternAction whose patterns match the list of ground terms (respectively to the next ConstraintAction whose Constraint evaluates to true).

- when there is no more PatternAction whose patterns match the list of subjects (respectively no more ConstraintAction whose Constraint evaluates to true), the `%match` instruction is finished, and the execution control is transferred to the next instruction.

The semantics of a match construct may remind the switch/case construct. However, there is a big difference. For instance, in Tom we can have patterns (list-patterns) that can match in several ways a subject. Informally, when considering the subject $conc(a(), b(), c())$, and the pattern $conc(\_^*, x, \_^*)$, there are three possible match for this problem: either $x = a()$, either $x = b()$, either $x = c()$. Note that $\_^*$ is a special *hole* which can capture any sublist of $conc(\ldots)$. The list-matching is also known as associative matching. Besides this, some other matching theories are supported in Tom.

When taking this new possibility into account, the evaluation of a `%match` construct gets a little bit more complex:

- given a PatternAction whose patterns match the list of ground terms (or a ConstraintAction whose Constraint is evaluated to true), the list of variables is instantiated and the associated semantic action is executed.

- if the execution control is not transferred outside the `%match` instruction, in addition to the previous explanations, if the considered matching theory may return several matches, for each match, the free variables are instantiated and the associated semantic action is executed. This means that the same action may be executed several times, but in a different context: i.e. the variables have different instantiations.

- when all matches have been computed (there is at most one match in the syntactic theory, i.e. when no special theory, as associativity for instance, is associated to the symbols used in the patterns), the execution control is transferred to the next PatternAction whose patterns match the list of ground terms (respectively to the next ConstraintAction whose Constraint evaluates to true).

- as before, when there is no more PatternAction whose patterns match the list of subject (or respectively no ConstraintAction whose Constraint evaluates to true), the `%match` instruction is finished, and the execution control is transferred to the next instruction.

As mentioned in the BNF-syntax, a *label* may be attached to a pattern. In that case, in C and Java, it becomes possible to exit from the current PatternAction (using a `goto` or a `break`), without exiting from the whole `%match` construct. The control is transferred to the next pattern which matches the subjects (respectively to the next constraint). This feature is useful to exit from a complex associative-matching for which, for any reason, we are no longer interested in getting other solutions.

Note: the behavior is not determined if inside an action the subjects of the `%match` instruction under evaluation are modified.

When using the new syntax based on constraints, there are several restrictions that are imposed by the compiler (an error is generated if they are not respected):

- no circular references among variables are allowed. For instance, something like `x << x` will generate an error. This verification works even when the cycles are less evident, like for instance for the following constraint: `f(g(x),a()) << y  && f(b(),y) << z  && g(f(z,c())) << x`.

- when using disjunctions, all the variables that are used in the action have to be found in each member of the disjunction (for ensuring that no non-instantiated variable is used in the action). For instance, using the following ConstraintAction generates an error: `x << s1 || y << s2 -> { /* code that uses y */ }`

10.2.3 Tom pattern

As we can imagine, the behavior of a `%match` construct strongly depends on the patterns which are involved. The formalism which defines the syntax of a pattern is also an essential component of Tom. But because there exist several ways to define patterns with equivalent behavior, its formal definition is not so simple. Although, the different shortcuts help the programmer to simplify the definitions of patterns.

Informally, a pattern is a term built with constructors and variables (please note that `x` denotes a variable, whereas `a()` is a constructor). A variable can also be anonymous, and it is denoted by _. Let's look at some examples of patterns: `x`, `a()`, `f(a())`, `g(a(),x)`, or `h(a(),_,x)`. When a pattern matches a subject, it may be useful to keep a reference to a matched subterm. The annotation mechanism (`z@g(y)` for example) can be used for this purpose. Thus, considering the matching between the pattern `f(x,z@g(y))` and the subject `f(a(),g(h(b())))`, `y` is instantiated by `h(b())`, and `z` is instantiated by `g(h(b()))`. This can be useful in C, to free the memory for example.

When identical actions have to be performed for a set of patterns which share a common structure, the *disjunction of symbols* may be used: pattern `(f|g)(a())` is equivalent to the set {`f(a())`, `g(a())`}. The disjunction of symbols may also be used in subterms, like in `h( (f|g)(x) )`.

More formally, a Tom pattern and a Tom term has the following syntax:

Term	::=	VariableName[‘*’]
	|	Name ‘(’[Term (‘,’ Term)*]‘)’
Pattern	::=	[AnnotedName ‘@’] PlainPattern
PlainPattern	::=	[‘!’]VariableName [‘*’]
	|	[‘!’] HeadSymbolList (ExplicitTermList | ImplicitPairList)
	|	ExplicitTermList
	|	‘_’
	|	‘_*’
	|	XMLTerm
HeadSymbolList	::=	HeadSymbol [‘?’]
	|	‘(’ HeadSymbol (‘|’ HeadSymbol)+ ‘)’
ExplicitTermList	::=	‘(’ [Pattern (‘,’ Pattern)*] ‘)’
ImplicitPairList	::=	‘[’ [PairPattern (‘,’ PairPattern)*] ‘]’
PairPattern	::=	SlotName ‘=’ Pattern

Concerning the Term syntax, both Tom and host-language variables can be used and Name can be either a function symbol declared in Tom or the name of a method from the host language.

Note: since version 2.4, negative patterns, called *anti-patterns* have been introduced. See section 10.2.4 for a detailed description.

A pattern is a term which could contain variables. When matching a pattern against a subject (a ground term), these variables are instantiated by the matching procedure (generated by Tom). In Tom, the variables do not have to be declared: their type is inferred automatically, depending on the context in which they appear.

As described previously, Tom offers several mechanisms to simplify the definition of a pattern:

- standard notation: a pattern can be defined using a classical prefix term notation. To make a distinction between variables and constants, the latter have to be written with explicit parentheses, like `x()`. In this case, the corresponding Tom operator (`%op x()`) should have been declared. When omitting parentheses, like `x`, this denotes a variable.

- unnamed variables: the `_` notation denotes an anonymous variable. It can be used everywhere a variable name can be used. It is useful when the instance of the variable does not need to be used. Similarly, the `_*` notation can be used to denote an anonymous list-variable. This last notation can improve the efficiency of list-matching because the instances of anonymous list-variables do not need to be built.

- annotated variable: the `@` operator allows to give a variable name to a subterm. In `f(x@g(_))` for example, `x` is a variable that will be instantiated by the instance of the subterm `g(_)`. The variable `x` can then be used as any other variable.

- implicit notation: as explained below, the `%op` operator forces to give name to arguments. Assuming that the operator `f` has two arguments, named `arg1` and `arg2`, then we can write the pattern `f[arg1=a()]` which is equivalent to `f(a(),_)`. This notation is interesting mostly when using constructors with many subterms. Besides that, using this notation can avoid changing the patterns when the signature slightly changes (the order of the arguments, adding a new argument etc).

- unnamed list operator: it is often the case that given a list-sort, only one list-operator is defined. In this case, when there is no ambiguity, the name of the operator can be omitted. Considering the `conc` list-operator for example (see `%oplist` and `%oparray` below), to improve the readability, the pattern `conc(_*,x,_*)` can be written `(_*,x,_*)`. This feature is particularly useful in the XML notation introduced in the following.

- symbol disjunction notation: to factorize the definition of pattern which have common subterms, it is possible to describe a family of patterns using a disjunction of symbols. The pattern `(f|g)(a(),b())` corresponds to the disjunction `f(a(),b())` or `g(a(),b())`. To be allowed in a disjunction (in standard notation), the constructors should have the same signature (arity, domain and codomain).

In practice, it is usually better to use the disjunction notation with the implicit notation Tom offers: (`(f|g)[arg1=a()]`). In that case, the signatures of symbols do not have to be identical: only involved slots have to be common (same names and types). Thus, the pattern `(f|g)[arg1=a()]` is correct, even if `g` has more slots than `f`: it only has to have the slot `arg1`, with the same sort.

Note: the disjunction of symbol can also be used in XML notation: `<(A|B)>...</(A|B)>`.

The use of '`?`' after a list operator enables real associative with neutral elements (AU) matchings. By using `conc?` for example, we simply specify that the subject may not start with a `conc` symbol. For instance, the following code would produce the output `matched`, because `x` and respectively `y` can be instantiated with the neutral element of `conc` (please see the documentation on Gom for further details about specifying symbols' type and their neutral elements).

```
L l = `a();
%match(l) {
  conc?(x*,y*) -> { System.out.println("matched"); }
}
```

Note that without the use of '`?`', the subject *must* start with a `conc` in order to have a match.

Note: since version 2.5 we can use, inside a list, a subpattern that also denotes a list; moreover, this subpattern can be annotated. For instance, patterns like `conc(_*,p@conc(a(),_*,b()),_*)` are now valid.

10.2.4 Tom anti-pattern

The notion of anti-pattern offers more expressive power by allowing complement constructs: a pattern can describe what *should not* be in the matched subject.

The notion of complement is introduced by the symbol '`!`', as illustrated by the following grammar fragment:

PlainPattern	::=	['`!`'] VariableName
	|	['`!`'] HeadSymbolList (ExplicitTermList | ImplicitPairList)
	|	...

The semantics of anti-patterns can be best understood when regarding them as complements. For example, a pattern like `car[color=blue()]` will match all the blue cars. If we add an '`!`' symbol, the anti-pattern `!car[color=blue()]` will match everything that is not a blue car, i.e all objects that are not cars or the cars that have a color different from blue. The grammar allows also `car[color=!blue()]` - matches all cars that are not blue, or `!car[color=!blue()]` - either everything that is not a car, or a blue car.

Using the non-linearity combined with anti-patterns allows to express interesting searches also. For example, `car[interiorColor=x,exteriorColor=x]` will match the cars that have the same interior and exterior color. By using the anti-pattern `car[interiorColor=x,exteriorColor=!x]`, the result is as one would expect: it will match all the cars with different interior - exterior colors.

It is also possible to use the anti-patterns in list constructions. Please refer to the tutorial for more examples.

Note: The use of annotations (`@`) is forbidden bellow a '`!`' symbol and is prevented by a compilation error. This is due to the fact that what is under this symbol generally will not match, therefore it cannot be used in the action part of the rules. You will also get an error if you try to put '`!`' before an '`_`' or '`_*`' because a construct like '`!_`' in a pattern will never match anything, therefore it is useless.

10.2.5 Backquote construct

Backquote construct (`) can be used to build an algebraic term or to retrieve the value of a Tom variable (a variable instantiated by pattern-matching).

BackQuoteTerm ::= [`` ` ``] CompositeTerm

The syntax of CompositeTerm is not fixed since it depends on the underlying language.

However, CompositeTerm should be of the following form:

- Name: to denote a Tom variable
- Name‘*’: to denote a Tom list-variable
- Name(...): to build a prefix term
- (...): to build an expression
- xml(...): to build an XML term

In general, it is sufficient to add a backquote before the term you want to build to have the desired behavior. The execution of `‘f(g(a()))` will build the term $f(g(a))$, assuming that f, g, and a are Tom operators. Suppose now that g is no longer a constructor but a function of the host-language. The construction `‘f(g(a()))` is still valid, but the semantics is the following: the constant a is built, then the function g is called, and the returned result is put under the constructor f. Therefore, the result of g must be a correct term, which belongs to the right type (i.e. the domain of f).

To simplify the interaction with the host-language, it is also possible to use “unknown symbols” like `f(x.g())` or `f(1+x)`. The scope of the backquote construct is determined by the scope of the most external enclosing braces, except in two case: `‘x` and `‘x*` which allow you to use variables instantiated by the pattern part. In that case the scope is limited to the length of the variable name, eventually extended by the `’*’`. Sometimes, when writing complex expression like `if(‘x==‘y || ‘x==‘z)`, it can be useful to introduce extra braces (`if( ‘(x==y || x==z) )`) in order to extend the scope of the backquote.

Note: since version 2.5, type inference is available when building lists. For instance, when building a list, the following code is now valid: `‘conc(f(...))` if the type of `f` is known by Tom — if previously declared using a `%op`. Before version 2.5, supposing that the type of `f` was `L`, one had to write: `L X = ‘f(...);‘conc(X*)`.

10.2.6 *Meta-quote* construct

Tom provides the construct ‘`%[`’ ... ‘`]%`’ that allows to build formatted strings without the need to encode special characters such as tabulations and carriage returns as it is usually done in Java. For example, to build a string containing the `HelloWorld` program, one can simply write:

```
String hello = %[
  public class Hello {
    public static void main(String[] args) {
      System.out.println("Hello\n\tWorld !");
    }
  }
]%
```

Additionally, it is possible to insert in this string the content of a `String` variable, or the result of a function call (if it is a `String`) using the ‘`@`’ as escape character: the code contained between ‘`@`’ in this construct will be evaluated and the result inserted in the surrounding formatted string. Then, to add to the `HelloWorld` example a version string, we can use:

```
String version = "v12";
String hello2=%[
  public class Hello {
    public static void main(String[] args) {
      System.out.println("Hello\n\tWorld   @version@");
    }
  }
]%;
```

Even if the contents of the *meta-quote* construct is a formatted string, it is required that this string contains correctly balanced braces.

Note: the expression between two ‘`@`’ can contain Tom constructs, like `backquote` constructs for example. **Note:** use ‘`@@`’ to insert the character ‘`@`’

10.3 Tom signature constructs (*)

10.3.1 Sort definition constructs

To define the mapping between the algebraic constructors and their concrete implementation, Tom provides a signature-mapping mechanism composed of several constructs. In addition to predefined mapping for usual builtin sorts (`int`, `long`, `double`, `boolean`, `string`, and `char`), all other algebraic sorts have to be declared using the `%typeterm` construct.

To use predefined sorts (in a `%match` construct or in the definition of a new operator), it is sufficient to use the `%include` construct (`%include { int.tom }` for example).

When defining a new type with the `%typeterm` construct, some information has to be provided:

- the `implement` construct describes how the new type is implemented. The host language part written between braces (`'{'` and `'}'`) is never parsed. It is used by the compiler to declare some functions and variables.
- the `is_sort(t)` construct specifies how to check the sort of an object of this type (in Java this is usually done with `instanceof`). It is only required when using this type in a `%match` construct.
- the `equals(t1,t2)` construct corresponds to a predicate (parameterized by two term variables). This predicate should return `true` if the terms are "equal". The `true` value should correspond to the builtin `true` value of the considered host language. This last optional predicate is used to compare builtin values and to compile non-linear left-hand sides.

Given a Java class `Person` we can define an algebraic mapping for this class:

```
%typeterm TomPerson {
  implement { Person }
  is_sort(t) { t instanceof Person }
  equals(t1,t2) { t1.equals(t2) }
}
```

Here, we assume that the method `equals` implements a comparison function over instances of `Person`. Note that we used `TomPerson` to make a clear distinction between algebraic sorts (defined in Tom) and implementation sorts (defined in Java, via the use of classes). In practice, we usually use the same name to denote both the algebraic sort and the implementation sort.

The grammar is the following:

IncludeConstruct	::=	'`%include`' '{' FileName '}'
GomConstruct	::=	'`%gom`' ['(' optionString ')'] '{' GomGrammar '}'
GoalLanguageBlock	::=	'{' BlockList '}'
TypeTerm	::=	'`%typeterm`' Type '{' KeywordImplement [KeywordIsSort] [KeywordEquals] '}'
KeywordImplement	::=	'`implement`' GoalLanguageBlock
KeywordIsSort	::=	'`is_sort`' GoalLanguageSortCheck
KeywordEquals	::=	'`equals`' '(' Name ',' Name ')' GoalLanguageBlock

Note: since version 2.6, the variables used in the host-code may be prefixed by a '`$`' sign. This allows the compiler to inline the definition, making the code often smaller and more efficient.

10.3.2 Constructor definition constructs

Once algebraic sorts are declared (using `%typeterm`), Tom provides a mechanism to define signatures for constructors of these sorts using `%op`, `%oplist` or `%oparray` constructs. When defining a new symbol with the `%op` construct, the user should specify the name of the operator, its codomain, and its domain. The later one is defined by a list of pairs (slot-name, sort).

Let us consider again the class `Person`, and let us suppose that an instance of `Person` has two fields (`name` and `age`), we can define the following operator:

```
%op TomPerson person(name:String, age:int)
```

In this example, the algebraic operator `person` has two slots (`name` and `age`) respectively of sorts `String` and `int`, where `String` and `int` are pre-defined sorts.

In addition to the signature of an operator, several auxiliary functions have to be defined:

- The `is_fsym(t)` { predicate(t) } construct is used to check if a term t is rooted by the considered symbol. The `true` value should correspond to the builtin `true` value of the considered host language (`true` in Java or Caml, and something different from `0` in C for example).
- The `make(t1,...,tn)` construct is parameterized by several variables (i.e. that should correspond to the arity of the symbol). A call to this `make` function should return a term rooted by the considered symbol, where each subterm correspond to the terms given in arguments to the function. When defining a constant (i.e. an operator without argument, `make` can be defined without braces: `make { ... }`).
- The `get_slot(slotName,t)` construct has to be defined for all slots of the signature. The implementation of these constructs should be such that the corresponding subterm is returned.

Coming back to our example, checking if an object t is rooted by the symbol `person` can be done by checking that t is an instance of the class `Person`. Building a `person` can be done via the Java function `new Person(...)`. Accessing to the slots `name` and `age` could be implemented by an access to the variables of the class `Person`. In practice, the following operator definition should work fine:

```
%op TomPerson person(name:String, age:int) {
  is_fsym(t)  { t instanceof Person }
  make(t1,t2) { new Person(t1,t2) }
  get_slot(name,t) { t.name } // assuming that 'name' is public
  get_slot(age,t)  { t.age  } // assuming that 'age' is public
}
```

When defining a new symbol with the `%oplist` construct, the user has to specify how the symbol is implemented. In addition, the user has to specify how a list can be built and accessed:

- the `make_empty()` construct should return an empty list.
- the `make_insert(e,l)` construct corresponds to a function parameterized by a list variable and a term variable. This function should return a new list `l'` where the element `e` has been inserted at the head of the list `l` (i.e. `equals(get_head(l'),e)` and `equals(get_tail(l'),l)` should be `true`).
- the `get_head(l)` function is parameterized by a list variable and should return the first element of the considered list.
- the `get_tail(l)` function is parameterized by a list variable and should return the tail of the considered list.
- the `is_empty(l)` constructs corresponds to a predicate parameterized by a list variable. This predicate should return `true` if the considered list contains no element.

Similarly, when defining a new symbol with the `%oparray` construct, the user has to specify how the symbol is implemented, how an array can be built, and accessed:

- the `make_empty(n)` construct should return a list such that `n` successive `make_append(e,l)` can be made.
- the `make_append(e,l)` construct corresponds to a function parameterized by a list variable and a term variable.

  Warning: This function should return a list `l'` such that the element `e` is at the end of `l`.

- the `get_element(l,n)` construct is parameterized by a list variable and an integer. This should correspond to a function that return the `n-th` element of the considered list `l`.

- the `get_size(l)` constructs corresponds to a function that returns the size of the considered list (i.e. the number of elements of the list). The size of an empty list is `0`.

The `%oplist` or `%oparray` is complex but not difficult to use. Let us consider the `ArrayList Java` class, and let us define a Tom mapping over this data-structure. The first thing to do consists in defining the sort for the elements and the sort for the list-structure:

```
%typeterm Object {
  implement     { Object        }
  equals(l1,l2) { l1.equals(l2) }
}
%typeterm TomList {
  implement     { ArrayList    }
  equals(l1,l2) { l1.equals(l2) }
}
```

Once defined the sorts, it becomes possible to define the list-operator `TomList conc( Object* )`. This operator has a variadic arity: it takes several `Object` and returns a `TomList`.

```
%oparray TomList conc( Object* ) {
  is_fsym(t)       { t instanceof ArrayList }
  make_empty(n)    { new ArrayList(n)       }
  make_append(e,l) { myAdd(e,(ArrayList)l)   }
  get_element(l,n) { (Object)l.get(n)        }
  get_size(l)      { l.size()                }
}

private static ArrayList myAdd(Object e,ArrayList l) {
  l.add(e);
  return l;
}
```

An auxiliary function `myAdd` is used since the `make_append` construct should return a new list. The `get_element` should return an element whose sort belongs to the domain (`Object`) in this example. Although not needed in this example, in general, a cast (`((Object)l.get(n))`) is needed.

The grammar for the mapping constructs is the following:

```
Operator              ::=  '%op' Type Name
                           '(' [ SlotName ':' Type ( ',' SlotName ':' Type )* ] ')'
                           '{' KeywordIsFsym ( KeywordMake | KeywordGetSlot )* '}'
OperatorList          ::=  '%oplist' Type Name '(' Type '*' ')'
                           '{' KeywordIsFsym ( KeywordMakeEmptyList
                           | KeywordMakeInsert | KeywordGetHead
                           | KeywordGetTail | KeywordIsEmpty )* '}'
OperatorArray         ::=  '%oparray' Type Name '(' Type '*' ')'
                           '{' KeywordIsFsym ( KeywordMakeEmptyArray |
                           KeywordMakeAppend | KeywordElement
                           | KeywordGetSize )* '}'
KeywordIsFsym         ::=  'is_fsym' '(' Name ')' GoalLanguageBlock
KeywordGetSlot        ::=  'get_slot' '(' Name ',' Name ')' GoalLanguageBlock
KeywordMake           ::=  'make' [ '(' Name ( ',' Name )* ')' ] GoalLanguageBlock
KeywordGetHead        ::=  'get_head' '(' Name ')' GoalLanguageBlock
KeywordGetTail        ::=  'get_tail' '(' Name ')' GoalLanguageBlock
KeywordIsEmpty        ::=  'is_empty' '(' Name ')' GoalLanguageBlock
KeywordMakeEmptyList  ::=  'make_empty' [ '(' ')' ] GoalLanguageBlock
KeywordMakeInsert     ::=  'make_insert' '(' Name ',' Name ')' GoalLanguageBlock
KeywordGetElement     ::=  'get_element' '(' Name ',' Name ')' GoalLanguageBlock
KeywordGetSize        ::=  'get_size' '(' Name ')' GoalLanguageBlock
KeywordMakeEmptyArray ::=  'make_empty' '(' Name ')' GoalLanguageBlock
KeywordMakeAppend     ::=  'make_append' '(' Name ',' Name ')' GoalLanguageBlock
```

Note: since version 2.5, `is_fsym` and `make` functions are optional (therefore the `%op` construct could be empty). When not declared, `is_fsym` default value is `false`. When nothing is declared, there is a `make` default value: a call to the function which has the same name as the considered operator. This shortcut is useful to provide type information about a Java function for example.

10.3.3 Predefined sorts and operators

See Section 13.1.

10.3.4 Gom construct

The grammar for the Gom construct is as follows:

```
GomConstruct  ::=  '%gom' ['(' optionString ')'] '{' GomGrammar '}'
```

It allows to define a Gom signature (for more details about Gom see Chapter 11). The Gom compiler is called on the GomGrammar, and the construct is replaced by the produced Tom mapping. The optionString is composed by a list of command line options to pass to the underlying Gom compiler, as described in section 16.1.

10.4 XML pattern

To deal with XML documents, the XML notation can be used (`<A><B attribute="name"/ ></A>` for example).

When manipulating XML documents, we distinguish two main kinds of operations: retrieving information and transforming a document. Tom provides three different XML notations that ought to simplify the definition of patterns: the "standard " and the "implicit" XML notations are used to define compact (but incomplete) patterns. This notation is well suited to retrieve information. The "explicit" XML notation is used to precisely describe an XML pattern and all the variables that have to be instantiated. This notation is particularly well suited to perform XML transformation since it allows the programmer to precisely describe how variables have to be instantiated.

To make the XML notation understandable, we have to explain how XML documents are handled by Tom. To each XML document corresponds a DOM (Document Object Model) representation. In Tom,

we have defined a mapping from DOM sorts to abstract algebraic sorts: `TNode` and `TNodeList`, which correspond respectively to `Node` and `NodeList`, defined by the Java DOM implementation.

Thus, a `Node` object becomes a ternary operator `Element` whose first subterm is the name of the XML node, the second subterm is a list of attributes and the third subterm is a list of subterms (which correspond to XML sub-elements). The second and the third elements are terms of sort `TNodeList` (because they are implemented by `NodeList` objects in DOM).

Thus, when considering the `<A></A>` XML document, the corresponding algebraic term is `Element("A",[],[])`, where `[]` denotes the empty list. Similarly, `<A><B attribute="name"/ ></A>` is encoded into `Element("A",[],[Element("B",[Attribute("attribute","name")],[])])`.

When defining an XML pattern, the user has to introduce extra list-variables to precisely describe the XML pattern and capture the different contexts. Suppose that we are interested in finding a node `<B></B>` which is a subterm of a node `<A></A>` (but not necessary the first subterm). The algebraic pattern should be `Element("A",[_*],[_*,Element("B",[_*],[_*]),_*])`. Using the XML notation, this pattern should be expressed as follows: `<A (_*)>(_*,<B (_*)>(_*)</B>,_*)</A>`. This notation (called explicit) is precise but error prone. This is why we have introduced the explicit notation, where all context variable can be removed (and `()` are replaced by `[]`): `<A []><B []>[]</B></A>`. The last notation (called standard XML notation) allows the user to remove the `[]` and replace the list-separator (`,`) by spaces. The previous pattern can be written: `<A><B></B></A>`.

These three different notations allow the user to choose the level of control he wants to have on the XML pattern matching algorithm.

The formal description of the syntax is the following:

XMLTerm	::=	'<' XMLNameList XMLAttrList '/>'
	|	'<' XMLNameList XMLAttrList '>' XMLChilds '</' XMLNameList '>'
	|	'#TEXT' '(' Identifier | String ')'
	|	'#COMMENT' '(' Identifier | String ')'
	|	'#PROCESSING-INSTRUCTION'
		'(' (Identifier | String) ',' (Identifier | String) ')'
XMLNameList	::=	XMLName
	|	'(' XMLName ('|' XMLName)* ')'
XMLAttrList	::=	'[' [XMLAttribute (',' XMLAttribute)*] ']'
	|	'(' [XMLAttribute (',' XMLAttribute)*] ')'
	|	(XMLAttribute)*
XMLAttribute	::=	'_*'
	|	VariableName '*'
	|	AttributeName '=' [AnnotedName '@'] (Identifier | String)
	|	[AnnotedName '@'] '_' '=' [AnnotedName '@'] (Identifier | String)
XMLChilds	::=	(Term)*
	|	'[' Term (',' Term)* ']'

Chapter 11

Gom

Gom is a generator of tree implementations in Java, allowing the definition of a preferred canonical form, using *hooks*. The tree implementations Gom generates are characterized by strong typing, immutability (there is no way to manipulate them with side-effects), maximal subterm sharing and the ability to be used with strategies.

11.1 Gom syntax

The basic functionality of Gom is to provide a tree implementation in Java corresponding to an algebraic specification.

Gom provides a syntax to concisely define abstract syntax tree, which is inspired from the algebraic type definition of ML languages.

Each Gom file consists in the definition of one or more modules. In each module we define sorts, and operators for the sorts. Additionally, it allows to define *hooks* modifying the default behavior of an operator.

```
GomGrammar          ::= Module
Module              ::= 'module' ModuleName [Imports] Grammar
Imports             ::= 'imports' (ModuleName)*
Grammar             ::= 'abstract syntax' (TypeDefinition | HookDefinition)*
TypeDefinition      ::= SortName '=' ['|'] OperatorDefinition ('|' OperatorDefinition)*
OperatorDefinition  ::= OperatorName '('[SlotDefinition(','SlotDefinition)*]')'
                      | OperatorName '(' SortName'*' ')'
SlotDefinition      ::= SlotName ':' SortName
ModuleName          ::= Identifier
SortName            ::= Identifier
OperatorName        ::= Identifier
SlotName            ::= Identifier
-------------------------------------------------------------------------------
HookDefinition      ::= HookType ':' HookOperation
HookType            ::= OperatorName
                      | 'module' ModuleName
                      | 'sort' SortName
HookOperation       ::= 'make' '(' [Identifier (',' Identifier)*] ')' '{' TomCode '}'
                      | 'make_insert' '(' Identifier ',' Identifier)* ')' '{' TomCode '}'
                      | 'make_empty' '('')' '{' TomCode '}'
                      | 'Free () {}'
                      | 'FL () {}'
                      | ('AU' |'ACU') '()' '{' ['`' term] '}'
                      | 'interface()' '{' Identifier (',' Identifier )* '}'
                      | 'import()' '{' JavaImports '}'
                      | 'block()' '{' TomCode '}'
                      | 'rules()' '{' RulesCode '}'
                      | 'graphrules(' Identifier ',' ('Identity' |'Fail')')''{' GraphRulesCode '}'
-------------------------------------------------------------------------------
RulesCode           ::= (Rule)*
Rule                ::= RulePattern '->' TomTerm ['if' Condition]
RulePattern         ::= [ AnnotedName '@' ] PlainRulePattern
PlainRulePattern    ::= ['!']VariableName [ '*' ]
                      | ['!']HeadSymbolList '(' [RulePattern ( ',' RulePattern )*] ')'
                      | '_'
                      | '_*'
-------------------------------------------------------------------------------
GraphRulesCode      ::= (GraphRule)*
GraphRule           ::= TermGraph '->' TermGraph ['if' Condition]
TermGraph           ::= [ Label ':' ] TermGraph
                      | '&' Label
                      | VariableName [ '*' ]
                      | HeadSymbolList '(' [TermGraph ( ',' TermGraph )*] ')'
Label               ::= Identifier
-------------------------------------------------------------------------------
Condition           ::= TomTerm Operator TomTerm
                      | RulePattern '<<' TomTerm
                      | Condition '&&' Condition
                      | Condition '||' Condition
                      | '(' Condition ')'
Operator            ::= '>' |'>=' |'<' |'<=' |'==' |'!='
```

11.1.1 Builtin sorts and operators

Gom supports several *builtin* sorts, that may be used as sort for new operators slots. To each of these builtin sorts corresponds a Java type. Native data types from Java can be used as builtin fields, as well as `ATerm` and `ATermList` structures. To use one of these builtin types in a Gom specification, it is required to add an import for the corresponding builtin.

Name	Java type
int	int
String	String
char	char
double	double
long	long
float	float
ATerm	aterm.ATerm
ATermList	aterm.ATermList

It is not possible to define a new operator whose domain is one of the builtin sorts, since those sorts are defined in another module.

Note: to be able to use a builtin sort, it is necessary to declare the import of the corresponding module (`int` or `String`) in the Imports section.

External Gom modules may be imported in a Gom specification, by adding the name of the module to import in the '`imports`' section. Once a module imported, it is possible to use any of the sorts this module declares or imports itself as type for a new operator slot. Adding new operators to an imported sort is however not allowed.

11.1.2 Example of signature

The syntax of Gom is quite simple and can be used to define many-sorted abstract-datatypes. The `module` section defines the name of the signature. The `imports` section defines the name of the imported signatures. The `abstract syntax` part defines the operators with their signature. For each argument, a sort and a name (called slot-name) has to be given.

```
module Expressions
imports String int

abstract syntax
Bool = True()
     | False()
     | Eq(lhs:Expr, rhs:Expr)
Expr = Id(stringValue:String)
     | Nat(intValue:int)
     | Add(lhs:Expr, rhs:Expr)
     | Mul(lhs:Expr, rhs:Expr)
```

The definition of a signature in Gom has several restrictions:

- there is no overloading: two operators cannot have the same name
- for a given operator, all slot-names must be different
- if two slots have the same slot-name, they must belong to the same sort. In the previous example, `Eq`, `Add`, and `Mul` can have a slot called `lhs` of sort `Expr`. But, `Id` and `Nat` cannot have a same slot named `value`, since their sort are not identical (the slots are respectively of sorts `String` and `int` for `Id` and `Nat`).

11.1.3 Combining Gom with Tom

A first solution to combine Tom with Gom is to use Gom as a standalone tool, using the command line tool or the ant task.

In that case, the module name of the Gom specification and the `package` option determine where the files are generated. To make things correct, it is sufficient to import the generated Java classes, as well as the generated Tom file. In the case of a Gom module called `Module`, all files are generated in a directory named `module` and the Tom program should do the following:

```
import module.*;
import module.types.*;

class MyClass {
  ...
  %include { module/Module.tom }
  ...
}
```

A second possibility to combine Tom with Gom is to use the `%gom` construct offered by Tom. In that case, the Gom module can be directly included into the Tom file, using the `%gom` instruction:

```
package myPackage;

import myPackage.myclass.expressions.*;
import myPackage.myclass.expressions.types.*;

class MyClass {
  %gom{
    module Expressions

    abstract syntax
    Bool = True()
         | False()
    ...
    Expr = Mul(lhs:Expr, rhs:Expr)
  }
  ...
}
```

Note that the Java code is generated in a package that corresponds to the current package, followed by the class-name and the module-name. This allows to define the same module in several classes, and avoid name clashes.

11.2 Hooks

Gom provides hooks that allow to define properties of the data-structure, in particular canonical forms for the terms in the signature in an algebraic way.

11.2.1 Algebraic rules

The '`rules`' hook ables to define a set of conditional rewrite rules over the current module signature. Those rules are applied systematically using a leftmost innermost strategy. Thus, the only terms that can be produced and manipulated in the Tom program are normal with respect to the defined system.

```
  module Expressions
  imports String int

  abstract syntax
  Bool = True()
       | False()
       | Eq(lhs:Expr, rhs:Expr)
  Expr = Id(stringValue:String)
       | Nat(intValue:int)
       | Add(lhs:Expr, rhs:Expr)
       | Mul(lhs:Expr, rhs:Expr)
```

```
module Expressions:rules() {
  Eq(x,x) -> True()
  Eq(x,y) -> False() if x!=y
}
```

Since the rules do alter the behavior of the construction functions in the term structure, it is required in a module that the rules in a '`rules`' hook have as left hand side a pattern rooted by an operator of the current module. The rules are tried in the order of their definitions, and the first matching rule is applied.

Note: It is possible to define rules on a variadic symbol. However, due to the leftmost innermost rule application strategy, using a list variable at the left of a pattern is usually not needed, and may result in an inefficient procedure.

11.2.2 Hooks to alter the creation operations

Hooks may be used to specify how operators should be created. '`make`', '`make_empty`' and '`make_insert`' hooks are altering the creation operations for respectively algebraic, neutral element (empty variadic) and variadic operators. '`make_insert`' is simply a derivative case of '`make`', with two arguments, for variadic operators.

The hook operation type is followed by a list of arguments name between '`()`'. The creation operation takes those arguments in order to build a new instance of the operator. Thus, the arguments number has to match the slot number of the operator definition, and types are inferred from this definition.

Then the body of the hook definition is composed of Java and Tom code. The Tom code is compiled using the mapping definition for the current module, and thus allows to build and match terms from the current module. This code can also use the `realMake` function, which consists in the "inner" default allocation function. This function takes the same number of arguments as the hook. In any case, if the hooks code does not perform a `return` itself, this `realMake` function is called at the end of the hook execution, with the corresponding hooks arguments

Using the `expression` example introduced in 11.1.2, we can add *hooks* to implement the computation of `Add` and `Mul` when both arguments are known integers (i.e. when they are `Nat(x)`)

```
module Expressions
imports String int

abstract syntax
Bool = True()
     | False()
     | Eq(lhs:Expr, rhs:Expr)
Expr = Id(stringValue:String)
     | Nat(intValue:int)
     | Add(lhs:Expr, rhs:Expr)
     | Mul(lhs:Expr, rhs:Expr)
Add:make(l,r) {
  %match(Expr l, Expr r) {
    Nat(lvalue), Nat(rvalue) -> {
      return `Nat(lvalue + rvalue);
    }
  }
}
Mul:make(l,r) {
  %match(Expr l, Expr r) {
    Nat(lvalue), Nat(rvalue) -> {
      return `Nat(lvalue * rvalue);
    }
  }
}
```

Using this definition, it is impossible to have an expression containing unevaluated expressions where a value can be calculated. Thus, a procedure doing constant propagations for `Id` whose value is known could simply replace the `Id` by the corresponding `Nat`, and rely on this mechanism to evaluate the expression. Note that the arguments of the `make` hook are themselves elements built on this signature, and thus the hooks have been applied for them. In the case of hooks encoding a rewrite system, this corresponds to using an innermost strategy.

11.2.3 List theory hooks

In order to ease the use of variadic operators with the same domain and co-domain, Gom does provide hooks that enforce a particular canonical form for lists.

- `FL`, activated with `<op>:FL() {}`, ensures that structures containing the operator `<op>` are left to right combs, with an empty `<op>()` at the right. This constitutes a particular form of associative with neutral element canonical form, with a restriction on the application of the neutral rules. This corresponds to the generation of the following normalisation rules:

```
make(Empty,tail)     -> tail
make(Cons(h,t),tail) -> make(h,make(t,tail))
make(head,tail)      -> make(head,make(tail,Empty)) if tail!=Empty and tail!=Cons
```

- `Free`, activated with `<op>:Free() {}`, ensures the variadic symbol remains free, i.e. deactivates the default `FL` hook.

- `AU`, activated with `<op>:AU() {}`, ensures that structures containing the `<op>` operator are left to right comb, and that neutral elements are removed. It is possible to specify an alternate neutral element to the associative with neutral theory, using `<op>:AU() {‘<elem>()}`, where `<elem>` is a term in the signature. This will generate the following normalisation rules:

```
make(Empty,tail)     -> tail
make(head,Empty)     -> head
make(Cons(h,t),tail) -> make(h,make(t,tail))
```

- `ACU` is similar to `AU`, except that it also ensures elements in the left to right comb are sorted using the builtin `compareTo` function.

```
make(Empty,tail)     -> tail
make(head,Empty)     -> head
make(Cons(h,t),tail) -> make(h,make(t,tail))
make(head,Cons(h,t)) -> make(head,Cons(h,t)) if head < h
make(head,Cons(h,t)) -> make(h,make(head,t)) if head >= h
```

If you do not define any hook of the form `AU`, `ACU`, `FL`, `Free`, or `rules`, the `FL` hook will be automatically declared for variadic operators those domain and co-domain are equals. In practice, this makes list matching and associative matching with neutral element easy to use.

If you use a hook `rules`, there may be an interaction that can lead to non-termination. Therefore, no hook will be automatically added, and you are forced to declare a hook of the form `AU`, `ACU`, `FL` or `Free`.

Note: if you do not really understand what happens when you define a hook `rules`, the safest approach is to declare the operator as `<op>:Free() {}` and to encode the desired theory in the `rules`.

11.3 Generated API

For each Module, the Gom compiler generates an API specific of this module, possibly using the API of other modules (declared in the Imports section). This API is located in a Java package named using the ModuleName lowercased, and contains the tree implementation itself, with some additional utilities:

- an abstract class named ModuleNameAbstractType is generated. This class is the generic type for all nodes whose type is declared in this module. It declares generic functions for all tree nodes: a `toATerm()` method returning a `aterm.ATerm` representation of the tree; a `symbolName()` method returning a `String` representation for the function symbol of the tree root; the `toString()` method, which returns a string representation.

```
public aterm.ATerm toATerm();
public String symbolName();
public int compareTo(Object o);
public int compareToLPO(Object o);
public void toStringBuilder(java.lang.StringBuilder buffer);
```

- in a subpackage `types`, Gom generates one class for each sort defined in the module, whose name corresponds to the sort name. Each sort class extends AbstractType for the module, and declares methods `boolean isOperatorName()` for each operator in the module (`false` by default). It declares getters (methods named `getSlotName()`) for each slot used in any operator of the sort (throwing an exception by default). A method `SortName fromTerm(aterm.ATerm trm)` is generated, allowing to use ATerm as an exchange format. The methods `SortName fromString(String s)` and `SortName fromStream(InputStream stream)` allow the use of an ATerm representation in String or stream form, to store terms in file and read them back.

```
public boolean is<op>();
public <SlotType> get<slotName>();
public <SortName> set<slotName>(<SlotType>);
public static <SortName> fromTerm(aterm.ATerm trm);
public static <SortName> fromString(String s);
public static <SortName> fromStream(java.io.InputStream stream) throws java.io.IOException;
public int length();
public <SortName> reverse();
```

- given a sort (SortName), generate a class (in a package `types.SortName`) for each operator. This class extends the class generated for the corresponding sort. It provides getters for the slots of the operator, and the `isOperatorName()` method is overridden to return `true`. Those classes implement the `tom.library.sl.Visitable` interface. It is worth noting that builtin fields are not accessible from the `Visitable`, and thus will not be visited by strategies. The operator class also implements a static `make` method, building a new instance of the operator. This `make` method is the only way to obtain a new instance.

```
public static <op> make(arg1,...,argn);
```

- for each list-operator, Operator for instance, the generated code contains two operator classes: one name EmptyOperator which is used to represent the empty list of arity 0, and the other named ConsOperator having two fields: one with the codomain sort, and one with the domain sort of the variadic operator, respectively named HeadOperator and TailOperator, leading to getter functions getHeadOperator and getTailOperator. This allows to define lists as the composition of many `Cons` and one `Empty` objects.

- for each module, one file ModuleName.tom providing a Tom mapping for the sorts and operators defined or imported by the module.

11.3.1 Example of generated API

We show elements of the generated API for a very simple example, featuring variadic operator. It defines natural numbers as `Zero()` and `Suc(n)`, and lists of natural numbers.

```
module Mod
abstract syntax
Nat = Zero()
    | Suc(pred:Nat)
    | Plus(lhs:Nat,rhs:Nat)
    | List(Nat*)
```

Using the command `gom Mod.gom`, the list of generated files is:

```
mod/Mod.tom                   (the Tom mapping)
mod/ModAbstractType.java
mod/types/Nat.java            (abstract class for the "Nat" sort)
mod/types/nat/List.java      \
mod/types/nat/ConsList.java   \
mod/types/nat/EmptyList.java  / Implementation for the operator "List"
mod/types/nat/Plus.java       (Implementation for "Plus")
mod/types/nat/Suc.java        (Implementation for "Suc")
mod/types/nat/Zero.java       (Implementation for "Zero")
```

The `ModAbstractType` class declares generic methods shared by all operators in the `Mod` module:

```
public aterm.ATerm toATerm()
public String symbolName()
public String toString()
```

The `mod/types/Nat.java` class provides an abstract class for all operators in the `Nat` sort, implementing the `ModAbstractType` and contains the following methods. First, the methods for checking the root operator, returning `false` by default:

```
public boolean isConsList()
public boolean isEmptyList()
public boolean isPlus()
public boolean isSuc()
public boolean isZero()
```

Then getter methods, throwing an `UnsupportedOperationException` by default, as the slot may not be present in all operators. This is convenient since at the user level, we usually manipulate objects of sort `Nat`, without casting them to more specific types.

```
public mod.types.Nat getpred()
public mod.types.Nat getlhs()
public mod.types.Nat getHeadList()
public mod.types.Nat getrhs()
public mod.types.Nat getTailList()
```

The `fromTerm` static method allows Gom data structure to be interoperable with `ATerm`
`public static mod.types.Nat fromTerm(aterm.ATerm trm)`

The operator implementations redefine all or some getters for the operator to return its subterms. It also provides a static `make` method to build a new tree rooted by this operator, and implements the `tom.library.sl.Visitable` interface. For instance, in the case of the `Plus` operator, the interface is:

```
public static Plus make(mod.types.Nat lhs, mod.types.Nat rhs)
public int getChildCount()
public tom.library.sl.Visitable getChildAt(int index)
public tom.library.sl.Visitable setChildAt(int index, tom.library.sl.Visitable v)
```

completed with the methods from the `Nat` class and the `ModAbstractType`.

The operators implementing the variadic operator both extend the `List` class, which provides list related methods, such as `length`, `toArray` and `reverse`. The `toArray` method produces an array of object of the codomain type corresponding to the list elements, while the `reverse` method returns the list with all elements in reverse order. The `List` class for our example then contains:

```
public int length()
public mod.types.Nat[] toArray()
public mod.types.Nat reverse()
```

For the `ConsList` class, we obtain:

```
/* the constructor */
public static ConsList make(mod.types.Nat _HeadList, mod.types.Nat _TailList) { ... }
public String symbolName() { ... }
/* From the "Nat" class */
public boolean isConsList() { ... }
public mod.types.Nat getHeadList() { ... }
public mod.types.Nat getTailList() { ... }
/* From the "ModAbstractType" class */
public aterm.ATerm toATerm() { ... }
public static mod.types.Nat fromTerm(aterm.ATerm trm) { ... }
/* The tom.library.sl.Visitable interface */
public int getChildCount() { ... }
public tom.library.sl.Visitable getChildAt(int index) { ... }
public tom.library.sl.Visitable setChildAt(int index, tom.library.sl.Visitable v) { ... }
/* The MuVisitable interface */
public tom.library.sl.Visitable setChilds(tom.library.sl.Visitable[] childs) { ... }
```

11.3.2 Hooks to alter the generated API

There exist four other hooks '`import`', '`interface`', '`block`' and '`mapping`' that offer possibilities to enrich the generated API. Contrary to '`make`' and '`make_insert`', these hooks have no parameters. Moreover, they can be associated not only to an operator but also to a module or a sort.

HookDefinition	::=	HookType '`:`' HookOperation
HookType	::=	OperatorName
	|	'`module`' ModuleName
	|	'`sort`' SortName
HookOperation	::=	'`interface()`' '{' Identifier ('`,`' Identifier)* '}'
	|	'`import()`' '{' JavaImports '}'
	|	'`block()`' '{' TomCode '}'
	|	'`mapping()`' '{' TomMapping '}'

There are few constraints on the form of the code in these hooks:

- for '`import`', the code is a well-formed block of Java imports.
- for '`interface`', the code is a well-formed list of Java interfaces.
- for '`block`', the code is a well-formed Java block which can contain Tom code.
- for '`mapping`', the code is a well-formed Tom block composed only of mappings.

The code given in the hook is just added at the correct position in the corresponding Java class:

- for a module ModuleName, in the abstract class named ModuleName`AbstractType` (for now, you can only use this hook with the current module),
- for a sort SortName, in the abstract class named SortName in the package types,
- for an operator OperatorName of sort SortName, in the class named SortName in the package types/SortName.

In the case of '`mapping`' hooks, the corresponding code is added to the mapping generated for the signature.

```
module Expressions
imports String int

abstract syntax
  Bool = True()
       | False()
       | Eq(lhs:Expr, rhs:Expr)
  Expr = Id(stringValue:String)
       | Nat(intValue:int)
       | Add(lhs:Expr, rhs:Expr)
       | Mul(lhs:Expr, rhs:Expr)

True:import() {
  import tom.library.sl.*;
  import java.util.HashMap;
}

sort Bool:interface() { Cloneable, Comparable }

module Expressions:block() {
  %include{ util/HashMap.tom }
  %include{ sl.tom }

  %strategy CollectIds(table:HashMap) extends Identity() {
    visit Expr {
      Id(value) -> {
        table.put(‘value,getEnvironment().getPosition());
      }
    }
  }

  public static HashMap collect(Expr t) {
    HashMap table = new HashMap();
    ‘TopDown(CollectIds(table)).apply(t);
    return table;
  }
}
```

11.4 Term-Graph rewriting (**)

A term-graph is a term where subterms can be shared and where there may be cycles. Gom offers support to define term-graphs and term-graph rule systems. There exist several ways to define term-graphs but in our case, we propose to represent term-graphs by terms with pointers. These pointers are defined by a relative path inside the term. All the formal definitions can be found in this paper.

11.4.1 Term-graph data-structures

When defining a Gom algebraic signature, it is possible to construct term-graphs on these signature using the option `--termgraph`. In this case, the signature is automatically extended to manage labels. For every sort `T`, two new constructors are added:

```
LabT(label:String,term:T)
RefT(label:String)
```

With these two new constructors, users can define term-graphs as labelled terms:

```
Term cyclicTerm = `LabTerm("l",f(RefTerm("l")));
Term termWithSharing = `g(RefTerm("a"),LabTerm("a",a()));
```

From this labelled term, users can obtain the term-graph representation with paths using the `expand` method. This method must be called before applying a term-graph strategy.

11.4.2 Term-graph rules

Using the hook `graphrules`, it is possible to define a set of term-graph rules. The left-hand and right-hand sides of these rules are term-graphs. A set of rules can only be associated to a given sort.

```
sort Term: graphrules(MyGraphStrat,Identity) {
  g(l:a(),&l) -> f(b())
  f(g(g(a(),&l),l:x)) -> g(ll:b(),&ll) if b()<<x
}
```

In the rules, sharings and cycles are not represented by the constructor `LabTerm` and `RefTerm` but using a light syntax. `l:t` is equivalent to `LabTerm(l,t)` and `&l` corresponds to `RefTerm(l)`.

Contrary to classical term-graph rewriting, it is possible to reuse a label from the left-hand side in the right-hand side in order to obtain side effects. This feature is inspired from Rachid Echahed's formalism.

```
sort Term: graphrules(SideEffect,Identity) {
  f(l:a()) -> g(&l,l:b())
}
```

This set of rules is translated into a Tom `%strategy` that can be used in a Tom program:

```
Term t = (Term) `g(RefTerm("a"),LabTerm("a",a())).expand();
`TopDown(Term.MyGraphStrat()).visit(t)
```

11.5 Strategies support (*)

The data structures generated by Gom do provide support for the strategy language of Tom. We assume in this section the reader is familiar with the strategies support of Tom as described in chapter 12, and illustrated in chapter 7 of the tutorial.

11.5.1 Basic strategy support

The data structure generated by the Gom compiler provide support for the *sl library* implementing strategies for Tom. It is thus possible without any further manipulation to use the strategy language with Gom data structures.

This strategy support is extended by the Gom generator by providing congruence and construction elementary strategies for all operators of the data structure. Those strategies are made available through a Tom mapping `_<module>.tom` generated during Gom compilation.

11.5.2 Congruence strategies

The congruence strategies are generated for each operator in the Gom module. For a module containing a sort

```
Term = | a()
       | f(lt:Term,rt:Term)
```

congruence strategies are generated for both `a` and `f` operators, respectively called `_a` and `_f`. The semantics of those elementary strategies is as follows:

(_a)[t]	⇒	t if t equals a, *failure* otherwise
(_f(s1,s2))[t]	⇒	f(t1',t2') if t = f(t1,t2), with (s1)[t1] ⇒t1' and (s2)[t2] ⇒t2', *failure* otherwise

Thus, congruence strategies allows to discriminate terms based on how they are built, and to develop strategies adopting different behaviors depending on the shape of the term they are applied to.

Congruence strategies are commonly used to implement a specific behavior depending on the context (thus, it behaves like a complement to pattern matching). For instance, to print all first children of an operator `f`, it is possible to use a generic `Print()` strategy under a congruence operator.

```
Strategy specPrint = `TopDown(_f(Print(),Identity()));
```

Also, congruence strategies are used to implement `map` like strategies on tree structures: Consider a signature with `List = Cons(e:Element,t:List) | Empty()`, then we can define a `map` strategy as:

```
Strategy map(Strategy arg) {
  return `mu(MuVar("x"),
    Choice(_Empty(),_Cons(arg,MuVar("x")))
  );
}
```

The congruence strategy generated for variadic operators is similar to the `map` strategy, and will apply its argument to all subterms of a variadic operator.

11.5.3 Construction strategies

Gom generated strategies' purpose is to allow to build new terms for the signature at the strategy level. Those strategies do not use the terms they are applied to, and simply create a new term. Their semantics is as follows:

(Make_a)[t]	⇒	a
(Make_f(s1,s2))[t]	⇒	f(t1,t2) if (s1)[null] ⇒t1 and (s2)[null] ⇒t2, *failure* otherwise

We can note that as the sub-strategies for `Make_f` are applied to the `null` term, it is required that those strategies are themselves construction strategies and do not examine their argument.

These construction strategies, combined with congruence strategies can be used to implement rewrite rules as strategies. For instance, a rule $f(a,b) \rightarrow g(a,b)$ can be implemented by the strategy:

```
Strategy rule = `Sequence(
  _f(_a(),_b()),
  _Make_g(_Make_a(),_Make_b())
);
```

Chapter 12

Strategies

To exercise some control over the application of the rules, rewriting based languages provide abstract ways by using reflexivity and the meta-level for Maude, or the notion of rewriting strategies as in Tom. Strategies such as `bottom-up`, `top-down` or `leftmost-innermost` are higher-order features that describe how rewrite rules should be applied (At each step, the strategy chooses which rule is applied and in which position inside the term).

In Tom, we have developed a flexible and expressive strategy language inspired by ELAN, Stratego, and JJTraveler where high-level strategies are defined by combining low-level primitives. For example, the `top-down` strategy is recursively defined by `Sequence(s,All(TopDown(s)))`. Users can define *elementary strategies* (corresponding to a set of rewriting rules) and control them using various combinators proposed in the sl library. This rich strategy language allows to easily define various kinds of term traversals.

In this chapter, first, we briefly present the sl library functioning. After that, we describe in detail every elementary strategies and strategy combinators. Then, we explain how the sl library can be used in combination with Gom structures.

Note: strategies are only supported in Java.

12.1 Overview

The package `tom.library.sl` is mainly composed by an interface `Strategy` and a class for each strategy combinator.

12.1.1 Strategy interface

Every strategy (elementary strategies or combinators) implements the `Strategy` interface. To apply a strategy on a term (generally called the subject), this interface offers two methods:

- `Visitable visitLight(Visitable)` visits the subject any in a light way (without environment)
- `Visitable visit(Visitable)` visits the subject any by providing the environment

A strategy can visit any `Visitable` object. Any term constructed using a Tom mapping or a Gom signature is `Visitable`. The first method `visitLight` is the most efficient because it does not manage any environment. Most of time, it is sufficient.The second method depends on an environment (see Section 12.1.2). The `visit(Visitable)` method behaves like `visitLight` but updates at each step an environment.

When applying on a term, a strategy returns a `Visitable` corresponding to the result. In case of failures, these two methods throw a `VisitFailure` exception.

12.1.2 Environment

An environment is composed of the current position and the current subterm where the strategy is applied. This object corresponds to the class `Environment` of the package `tom.library.sl` and can be associated to a strategy using `setEnvironment(Environment)` and accessed using `getEnvitonment()`.

A position in a term is a sequence of integers that represents the path from the root of the term to the current subterm where the strategy is applied.

The method `getPosition()` in the `Environment` class returns a `Position` object that represents the current position. Due to the method `getSubject()`, users can also get the current subterm where the strategy is applied.

To retrieve all this information from a strategy, the `visit` method is necessary.

12.2 Elementary strategy

12.2.1 Elementary strategies from sl

An elementary strategy corresponds to a minimal transformation. It could be *Identity* (does nothing), *Fail* (always fails), or a set of *rewrite rules* (performs an elementary rewrite step only at the root position). In our system, strategies are type-preserving and have a default behavior (introduced by the keyword `extends`)

The first two elementary strategies are the identity and the failure. There are defined by two corresponding classes in *sl library*: `Identity` and `Fail`. These two strategies have no effect on the term. The identity strategy returns the term unchanged. The failure strategy throws a `VisitFailure` exception.

12.2.2 Elementary strategies defined by users

Users can define elementary strategies by using the `%strategy` construction. This corresponds to a list of `MatchStatement` (one associated to each sort) and can be schematically seen as a set of rewriting rules.

Here is the `%strategy` grammar:

StrategyConstruct	::=	'%strategy' StrategyName '(' [StrategyArguments] ')'
		'extends' ['`'] Term '{' StrategyVisitList '}'
StrategyArguments	::=	SubjectName ':' AlgebraicType (',' SubjectName ':' AlgebraicType)*
		|AlgebraicType SubjectName (',' AlgebraicType SubjectName)*
StrategyVisitList	::=	(StrategyVisit)*
StrategyVisit	::=	'visit' AlgebraicType '{' (VisitAction)* '}'
VisitAction	::=	[LabelName':'] PatternList '->' ('{' BlockList '}' |Term)

This strategy has a name, followed with mandatory parenthesis. Inside these parenthesis, we have optional parameters.

The strategy has an `extendsTerm` which defines the behavior of the default strategy that will be applied. In most cases, two default behaviours are used:

- the failure: `Fail()`
- the identity: `Identity()`

Note that this default behaviour is executed if no rule can be applied or if there is no Java `return` statement executed in the applied rules.

The body of the strategy is a list of visited sorts. Each `StrategyVisit` contains a list of `VisitAction` that will be applied to the corresponding sort. A `VisitAction` is either a `PatternAction` or simply a `Term` (equivalent to the `VisitAction` { `return Term;`}). In other words, a `StrategyVisit` is translated into a `MatchStatement`.

For instance, here is an elementary strategy `RewriteSystem` that can be instantiated as follows:

```
%strategy RewriteSystem() extends Identity() {
  visit Term {
    a() -> { return `b(); }
    b() -> { return `c(); }
  }
}

Strategy rule = `RewriteSystem();
```

Trick
A strategy can receive data as arguments. They must correspond to an algebraic type. To use a strategy as argument, use the type `Strategy`. To use a Java type, such as `HashSet` for example, it is sufficient to define an elementary mapping. This can be done as follows:

```
%include { util/types/HashSet.tom }

%strategy RewriteSystem(hs:HashSet) extends Identity() {
  visit Term {
    a() -> { hs.add(‘a()); }
    b() -> { return ‘c(); }
  }
}
```

The `RewriteSystem` strategy can be instantiated as follows:

```
HashSet hashset = new HashSet();
Strategy rule =‘RewriteSystem(hashset);
```

Strategies defined by ‘`%strategy`’ are local to the file defining them. If you want to export your strategy to another package, you have to create a public function exporting an instance of the strategy built with ‘‘’.

Note: you cannot use `%strategy` inside a function.

12.3 Basic strategy combinators

The following operators are the key-component that can be used to define more complex strategies. In this framework, the application of a strategy to a term can fail. In Java, the *failure* is implemented by an exception (`VisitFailure`) of the package `library.sl`.

(Identity)[t]	⇒	t
(Fail)[t]	⇒	*failure*
(Sequence(s1,s2))[t]	⇒	*failure* if (s1)[t] fails
		(s2)[t’] if (s1)[t] ⇒t’
(Choice(s1,s2))[t]	⇒	t’ if (s1)[t] ⇒t’
		(s2)[t] if (s1)[t] fails
(All(s))[f(t1,...,tn)]	⇒	f(t1’,...,tn’) if (s)[t1] ⇒t1’, ..., (s)[tn] ⇒tn’
		failure if there exists i such that (s)[ti] fails
(All(s))[cst]	⇒	c
(One(s))[f(t1,...,tn)]	⇒	f(t1,...,ti’,...,tn) if (s)[ti] ⇒ti’
		failure (s)[t1] fails, ..., (s)[tn] fails
(One(s))[cst]	⇒	*failure*

For example, we can define myFirstStrat = ‘All(RewriteSystem) where Rewritesystem is defined as the elementary strategy:

```
%strategy RewriteSystem() extends Fail() {
  visit Term {
    a() -> { return ‘b(); }
  }
}
```

When applying this strategy to different subjects, we obtain:

(myFirstStrat)[f(a(),a())]	⇒	f(b(),b())
(myFirstStrat)[f(a(),b())]	⇒	*failure*
(myFirstStrat)[b()]	⇒	b()

Sometimes, it is interesting to get the environment where the strategy is applied. The interface `Strategy` each strategy do implement provides a method `getEnvironment()` to get the current environment of the strategy. In particular, it is interesting when you want to collect the current position where the strategy is applied. In this case, you can call `getEnvironment().getPosition()`.

This information is also available through the `getEnvironment()` method from the `AbstractStrategy` class. To use this method or the following strategies which depend on it, you must call the `visit` method on your strategy instead of `visitLight`. That is the difference between `visitLight` and `visit`. Only the `visit` method maintain an environment.

```
try {
  Strategy s = `OnceBottomUp(rule);
  s.visit(subject));
} catch(VisitFailure e) {
  System.out.prinltn("Failure at position" + s.getEnvironment().getPosition());
}
```

The library gives several basic strategies using the position:

(Omega(i,s))[f(t1,...,tn)]	⇒	f(t1,...,ti',...,tn) if (s)[ti] ⇒ti'
		failure if (s)[ti] fails
(getEnvironment().getPosition().getReplace(i,t))[f(t1,...,tn)]	⇒	f(t1,...,t,...,tn)
(getEnvironment().getPosition().getSubterm(i,t))[f(t1,...,tn)]	⇒	ti

Note: the static method getEnvironment().getPosition().getReplace(i,t) corresponds to the strategy Omega(i,s) where s is a strategy reduced to one rule $x \rightarrow t$.

Note: the static method getEnvironment().getPosition().getReplace(i,t) returns a strategy that is not type preserving.

12.4 Strategy library

In order to define recursive strategies, we introduce the μ abstractor. This allows to give a name to the current strategy, which can be referenced later.

Try(s)	=	Choice(s,Identity)
Repeat(s)	=	μ x.Choice(Sequence(s,x),Identity())
OnceBottomUp(s)	=	μ x.Choice(One(x),s))
BottomUp(s)	=	μ x.Sequence(All(x),s))
TopDown(s)	=	μ x.Sequence(s,All(x)))
Innermost(s)	=	μ x.Sequence(All(x),Try(Sequence(s,x))))

The Try strategy never fails: it tries to apply the strategy s. If it succeeds, the result is returned. Otherwise,the Identity strategy is applied, and the subject is not modified.

The Repeat strategy applies the strategy s as many times as possible, until a failure occurs. The last unfailing result is returned.

The strategy OnceBottomUp tries to apply the strategy s once, starting from the leftmost-innermost leaves. BottomUp looks like OnceBottomUp but is not similar: s is applied to all nodes, starting from the leaves. Note that the application of s should not fail, otherwise the whole strategy also fails.

The strategy Innermost tries to apply s as many times as possible, starting from the leaves. This construct is useful to compute normal forms.

For example, we define myFirstInnerMost = InnerMost(s) where s is defined as the elementary strategy:

```
%strategy RewriteSystem() extends Fail() {
  visit Term {
    a()        -> { return `b(); }
    b()        -> { return `c(); }
    g(c(),c()) -> { return `c(); }
  }
}
```

The application of this strategy to different subject terms gives:

(myFirstInnerMost)[g(a(),b())]	⇒	c()
(myFirstInnerMost)[f(g(g(a,b),g(a,a)))]	⇒	f(c(),c())
(myFirstInnerMost)[g(d(),d())]	⇒	g(d(),d())

We can notice that Innermost strategy never fails. If we try myFirstBottomUp = BottomUp(s) with the same subjects, we obtain always *failure* because if s fails on a node, the whole strategy fails.

12.5 Strategies with identity considered as failure (*)

In order to get more efficient strategies (in particular when performing leftmost-innermost normalization), we consider variants where the notion of *failure* corresponds to the *identity*. This means that when a term cannot can be transformed by a strategy (into a different term), this is considered as a *failure*.

(SequenceId(s1,s2))[t]	⇒	(s2)[t'] if (s1)[t] ⇒t' with t≠t' t otherwise
(ChoiceId(s1,s2))[t]	⇒	t' if (s1)[t] ⇒t' with t≠t' (s2)[t] otherwise
(OneId(s))[f(t1,...,tn)]	⇒	f(t1,...,ti',...,tn) if (s)[ti] ⇒ti' with ti≠ti' f(t1,...,tn) otherwise
(OneId(s))[cst]	⇒	cst
TryId(s)	=	s
RepeatId(s)	=	μ x.SequenceId(s,x))
OnceBottomUpId(s)	=	μ x.ChoiceId(OneId(x),s))
OnceTopDownId(s)	=	μ x.ChoiceId(s,OneId(x)))
InnermostId(s)	=	μ x.Sequence(All(x),SequenceId(s,x)))
OutermostId(s)	=	μ x.Sequence(SequenceId(s,x),All(x)))

We can define a strategy trying to apply a simple rewrite system to the root of a term, replacing `a()` by `b()`, `b()` by `c()`, and `g(c(),c())` by `a()`, and otherwise returning the identity:

```
import tom.library.sl.*;
```

We also need to import the corresponding mapping:

```
%include { sl.tom }
```

Then we define an elementary strategy:

```
%strategy RewriteSystem() extends Fail() {
  visit Term {
    a()        -> { return `b(); }
    b()        -> { return `c(); }
    g(c(),c()) -> { return `c(); }
  }
}
```

Then, it becomes quite easy to define various strategies on top of this elementary strategy:

```
Term subject = `f(g(g(a,b),g(a,a)));
Strategy rule = `RewriteSystem();
try {
  System.out.println("subject       = " + subject);
  System.out.println("onceBottomUp  = " +
      `OnceBottomUp(rule).visitLight(subject));
  System.out.println("innermost   = " +
      `Choice(BottomUp(rule),Innermost(rule)).visitLight(subject));
} catch (VisitFailure e) {
  System.out.println("reduction failed on: " + subject);
}
```

12.6 Congruence strategies (generated by Gom)

As mentioned section 11.5, Gom automatically generates congruence and construction strategies for each constructor of the signature.

12.7 Matching and visiting a strategy (*)

Strategies can be considered as algebraic terms. For instance, the `BottomUp(v)` strategy corresponds to the algebraic term `mu(MuVar("x"),Sequence(v,All(MuVar("x"))))`.

Those strategy terms can then be traversed and transformed by mean of strategies. As strategies are considered as algebraic terms, it is possible to use pattern matching on the elementary strategies of the strategy language.

The following function uses pattern matching on a strategy expression, to identify a `TopDown` strategy and transform it to `BottomUp`.

```
public Strategy topDown2BottomUp(Strategy s) {
  %match(s) {
    Mu(x,Sequence(v,All(x))) -> {
      return `Mu(x,Sequence(All(x),v));
    }
  }
  return s;
}
```

Strategy expressions being visitable terms, we can also use the '`%strategy`' construction to define strategy transformations, for example, removing unnecessary `Identity()` strategies.

```
%strategy RemId extends Identity() {
  visit Strategy {
    Sequence(Identity(),x) -> { return `x; }
    Sequence(x,Identity()) -> { return `x; }
  }
}
```

12.8 Applying a strategy on a user defined data-structures (*)

The simplest way to use strategies is to apply them on data-structures generated by Gom, as this data structure implementation provides the interfaces and classes needed to use '`%strategy`'. In particular, all the data structure classes implement the `tom.library.sl.Visitable` interface used as argument of `visit` methods in the `tom.library.sl.Strategy` interface. However, it is also possible to use '`%strategy`' with any term implementation.

We detail here on a simple example of hand written data structure and how to use '`%strategy`' statements and the Tom strategy library.

Given a Java class `Person` we can define an algebraic mapping for this class:

```
 %typeterm TomPerson {
   implement { Person }
   equals(t1,t2) { t1.equals(t2) }
 }
```

For this example, we consider a data-structure those Gom equivalent could be

```
Term = A()
     | B()
     | G(arg:Slot)
     | F(arg1:Term, arg2:Term)
Slot = Name(name:String)
```

12.8.1 Simple implementation of the data structure

We first present a very straightforward implementation of this data structure. It will serve as a basis and will be extended to provide support for strategies.

We first define abstract classes for the two sorts of this definition, `Term` and `Slot`, and classes for those operators extending those sort classes.

```
public abstract class Term { }
public abstract class Slot { }

/* A and B are similar up to a renaming */
public class A extends Term {
  public String toString() {
    return "A()";
  }
  public boolean equals(Object o) {
    if(o instanceof A) {
      return true;
    }
    return false;
  }
}

/* G is similar to F, but has only one child */
public class F extends Term {
  public Term a;
  public Term b;
  public F(Term arg0, Term arg1) {
    a = arg0;
    b = arg1;
  }
  public String toString() {
    return "F("+a.toString()+", "+b.toString()+")";
  }
  public boolean equals(Object o) {
    if(o instanceof F) {
      F f = (F) o;
      return a.equals(f.a) && b.equals(f.b);
    }
    return false;
  }
}

public class Name extends Slot {
  public String name;
  public Name(String s) {
    this.name = s;
  }
  public String toString() {
    return "Name("+name+")";
  }
  public boolean equals(Object o) {
    if(o instanceof Name) {
      Name n = (Name) o;
      return name.equals(n.name);
    }
    return false;
```

```
  }
}
```

We only took care in this implementation to get a correct behavior for the `equals` method. Then, the Tom mapping is simply

```
%include { string.tom }
%typeterm Term {
  implement { Term }
  equals(t1,t2) {t1.equals(t2)}
}
%typeterm Slot {
  implement { Slot }
  equals(t1,t2) {t1.equals(t2)}
}
%op Term A() {
  is_fsym(t) { (t!= null) && (t instanceof A) }
  make() { new A() }
}
%op Term F(arg1:Term, arg2:Term) {
  is_fsym(t) { (t!= null) && (t instanceof F) }
  get_slot(arg1,t) { ((F) t).a }
  get_slot(arg2,t) { ((F) t).b }
  make(t0, t1) { new F(t0, t1) }
}
...
%op Slot Name(name:String) {
  is_fsym(t) { (t!= null) && (t instanceof Name) }
  get_slot(name,t) { ((Name) t).name }
  make(t0) { new Name(t0) }
}
```

12.8.2 Visiting data-structures by introspection

If the classes representing operators do not implement the `tom.library.sl.Visitable` interface, there is no special code modification for supporting strategies. Users have just to activate the Tom option `--gi`.

We can use the `tom.library.sl.Introspector` interface to apply strategies on such terms:

```
public Object setChildren(Object o, Object[] children);
public Object[] getChildren(Object o);
public Object setChildAt( Object o, int i, Object child);
public Object getChildAt(Object o, int i);
public int getChildCount(Object o);
```

In the `tom.library.sl.Strategy` interface, there exist corresponding methods to visit objects that do not implement the `tom.library.sl.Visitable` interface:

```
public Object visit(Object any, Introspector i) throws VisitFailure;
public Object visitLight(Object any, Introspector i) throws VisitFailure;
public Object visit(Environment envt, Introspector i) throws VisitFailure;
```

In the implementation of these methods, the introspector behaves like a proxy to render any object visitable. When activating the Tom option `--gi`, the compiler generates in each Tom class an inner class named `LocalIntrospector` that implements the `tom.library.sl.Introspector` interface. This class uses informations from the mappings to know how visiting the corresponding classes.

For example, we can define the following '`%strategy`' statement:

```
%strategy Rename(oldname:String,newname:String) extends Identity() {
  visit Slot {
    Name(n) -> {
      if(n.equals(oldname)) {
        return `Name(newname);
      }
    }
  }
}
```

Then by using the generated class `LocalIntrospector`, it is possible to use the strategy `Rename` with any strategy combinators:

```
public static void main(String[] args) {
  Term t = `F(F(G("x"),G("y")),G("x"));
  `TopDown(Rename("x","z")).visit(t, new LocalIntrospector());
}
```

Chapter 13

Runtime Library

13.1 Predefined mappings

13.1.1 Builtin sorts

The system comes with several predefined signature-mappings for C, Java and Caml. Among them, let us mention:

- `boolean.tom` (true or false)
- `char.tom` (written 'a', 'b', *etc.*)
- `double.tom` (using Java grammar for double)
- `float.tom` (using Java grammar for float)
- `int.tom` (written 1, 2, 3, *etc.*)
- `long.tom` (written 1l or 1L, *etc.*)
- `string.tom` (written "a", "ab", *etc.*)

These mappings define, for each builtin sort of the host language, an algebraic sort that can be used in a `%match` or a signature definition construct. Thus, builtin values, such as `f(5)`, `g('a')` or `h("foo")`, can be used in patterns.

The `string.tom` mapping is interesting because it provides an associative operator (`concString`) which allows the programmer to consider a string as a list of characters. Thus, the string `"foo"` can be seen as the algebraic object `concString('f','o','o')`. By using this mapping, it becomes possible to perform pattern matching against the content of a string. The pattern `concString('f',X*)` will match any string which begins with the character `'f'`. By using the unnamed-symbol capability, this pattern can be written: `('f',X*)` instead of `concString('f',X*)`.

To match any string which begins with the substring `"fo"`, the corresponding pattern should be `('f','o',X*)`. To simplify the definitions of such patterns, Tom supports an exception which allows the programmer to write `('fo',X*)` instead. Internally, the ill-formed character `'fo'` is expanded into the list `('f','o')`.

In addition to these mappings, several other predefined mappings come with the system:

- `aterm.tom` and `atermlist.tom` provide a mapping to the C and Java version of the ATerm Library
- `caml/list.tom` provides a mapping to the builtin notion of List in Caml
- `java/dom.tom` provides a mapping to the Java version of the DOM Library

13.1.2 Java

To help manipulating Java data-structures, Tom provides several mappings for the Java Runtime Library. The naming convention follows Java's one:

```
java
o--- Character.tom
+--- util
     o--- ArrayList.tom
     o--- HashMap.tom
     o--- HashSet.tom
     o--- LinkedList.tom
     o--- MapEntry.tom
     o--- TreeMap.tom
     o--- TreeSet.tom
     +--- types
          o--- AbsractCollection.tom
          o--- AbsractList.tom
          o--- AbsractSequentialList.tom
          o--- AbsractSet.tom
          o--- ArrayList.tom
          o--- Collection.tom
          o--- HashMap.tom
          o--- HashSet.tom
          o--- LinkedHashSet.tom
          o--- Map.tom
          o--- Object.tom
          o--- Stack.tom
          o--- TreeMap.tom
          o--- TreeSet.tom
          o--- Vector.tom
          o--- WeakHashMap.tom
```

The directory `types` contains only `%typeterm` declarations.

13.2 Strategies

To support strategies, Tom provides a runtime library, called SL and implemented in `strategy.jar`. This library implements the elementary strategy combinators (Identity, Fail, All, One, Choice, Sequence, etc.) as well as basic support for the computation of positions described in section 12.1.2.

In addition, some predefined mapping are also available to allow the description of strategies:

- `sl.tom`: maps the basic strategies classes, and provides a `mu` operator to express the recursion as well a `MuVar(v:String)` operator to allow the definition of complex strategies as described in Section 12.4.

13.3 Term viewer

The class `tom.library.utils.Viewer` contains a set of methods to visualize visitable terms.

```
/* dot representations */
// on the writer stream
public static void toDot(tom.library.sl.Visitable v, Writer w)
// on the standard output stream
public static void toDot(tom.library.sl.Visitable v)

/* pstree-like representations */
```

```
// on the writer stream
public static void toTree(tom.library.sl.Visitable v, Writer w)
// on standard output stream
public static void toTree(tom.library.sl.Visitable v)

/* gui display */
public static void display(tom.library.sl.Visitable v)
```

Note that these methods can also be used on strategies as they are also visitable.

13.4 XML

To support the transformation of XML documents, Tom provides a specific syntax for defining patterns, as well as several predefined mappings:

- `dom.tom`: maps XML notation to a Java implementation of the DOM library
- `dom_1.5`.tom: maps XML notation to a Java (version 1.5) implementation of the DOM library
- `TNode.tom`: maps XML notation to an ATerm based representation, generated by Gom

See Section 10.4 for a detailed description of the XML facilities offered by Tom.

13.5 Bytecode transformation (*)

To manipulate Java classes, Tom provides a library which supplies a Gom term usable by Tom out of a Java class. The library enables to define transformations of this term by strategic rewriting as well as functionalities to generate a new Java class from the modified term.

This approach is similar to BCEL library in the sense that we construct a complete representation of the class. But thanks to Gom, we obtain a very efficient structure with maximal sharing. Moreover, thanks to associative matching, we can easily express patterns on the bytecode and in this way, ease the definition of transformations.

The library generates a Gom term using the ASM library. This term is a memory-efficient representation of the Java class, which can then be traversed and transformed using Tom. After translating the Java class into a Gom term, we use Tom features to define transformations and traversals and to obtain a new Gom term which can be transformed into a new Java class.

13.5.1 Predefined mapping

To support the analysis and transformation of Java bytecode programs, Tom provides several mappings:

- `adt/bytecode/Bytecode.tom` provides an abstract syntax tree implementation to represent any Java bytecode program.
- `adt/bytecode/_Bytecode.tom` contains the congruence strategies associated to the AST.
- `java/bytecode/cfg.tom` defines new strategies that allows to explore the control flow graph.

13.5.2 Java classes as Gom terms

In order to represent bytecode programs, we have defined a Gom signature that allows us to represent any bytecode program by a typed term. Given a Java class, we use ASM to read the content and build an algebraic representation of the complete Java class. This approach is similar to BCEL. Contrary to ASM, this permits multi-pass or global analysis.

```
module Bytecode
imports int long float double String
abstract syntax
TClass = Class(info:TClassInfo, fields:TFieldList,
                methods:TMethodList)
...
TMethodList = MethodList(TMethod*)
TMethod = Method(info:TMethodInfo, code:TMethodCode)
TMethodCode = MethodCode(instructions:TInstructionList,
                         localVariables:TLocalVariableList,
                         tryCatchBlocks:TTryCatchBlockList)
...
TInstructionList = InstructionList(TInstruction*)
TInstruction = Nop()
             | Iload(var:int)
             | Ifeq(label:TLabel)
             | Invokevirtual(owner:String, name:String,
                             methodDesc:TMethodDescriptor)
 ...
```

The real signature (`adt/bytecode/Bytecode.tom`) contains more than 250 different constructors. The given signature shows that a class is represented by a constructor `Class`, which contains information such as name, packages, and imports. It also contains a list of fields and a list of methods. The latter is encoded using an associative operator `MethodList`. Similarly, a list of instructions is represented by the associative operator `InstructionList`. A method contains an `info` part and a `code` part. The `code` part is mainly composed by local variables and a list of instructions. Each bytecode instruction is represented by an algebraic constructor: `Nop`, `Iload`, *etc.*

In the package `tom.library.bytecode`, there exist two principal classes based on the ASM library:

- the `BytecodeReader` class whose constructor takes the path of a `Java` class. Its main method is `getTClass()` that returns the Gom representation of the `Java` class.
- the `BytecodeGenerator` class whose main method named `toBytecode(TClass c)` returns a byte array that corresponds to the Bytecode of the Gom term `c`.

```
public static byte[] transform(String file){
  BytecodeReader br = new BytecodeReader(file);
  TClass c = br.getTClass();
  TClass cc = transform(c);
  BytecodeGenerator bg = new BytecodeGenerator();
  return bg.toBytecode(cc);
}
```

13.5.3 Simulation of control flow by Strategies

When considering a Bytecode program, with the `sl` library, we can just define traversals without considering the control flow. Our suggestion is to use strategies in order to simulate the control flow during the traversal of the list of instructions. In the Tom language, the rules and the control are completely separated so an alternative for representing control flow graphs (CFG) is to use the control to indicate what is the possible following instruction. We have seen in the previous section that to apply a strategy to children, there exist two combinators `All` and `One`.

In the mapping `bytecode/cfg.tom`, the two combinators `AllCfg` and `OneCfg` behave almost as `All` and `One` but the considered children are the following instructions in the Control flow graph instead of the following instruction in the list. For example, the `Goto` instruction has one child with respect to the control flow graph (the instruction corresponding to the label). An `If_XX` instruction has two children: the one which satisfies the expression, and the one that does not.

Part IV

Tools

Chapter 14

Installation

This chapter describes how to install and use the Tom system.

14.1 Requirements

Tom is a Java application written with JDK 1.5. Tom is platform independent and runs on various systems. It has been used successfully on many platforms, including Linux (Debian, Mandrake, Ubuntu), FreeBSD, NetBSD, MacOS X, and Windows XP.

The only requirement to run Tom is to have a recent Java Runtime Environment installed (version 1.5 or newer) and/or the Eclipse platform (3.2 or newer). In addition, Ant can be useful to compile the system and the examples:

- Java is available for download at java.sun.com.
- Eclipse is available for download at www.eclipse.org
- Ant is available for download at ant.apache.org

14.2 Installing Tom

The binary distribution of Tom consists of the following directory layout:

```
tom
 +--- bin  // contains launcher scripts
 +--- lib  // contains Tom jars and necessary dependencies
 |     +--- runtime (BSD Licence)
 |     +--- tom (GPL Licence)
 |     +--- tools
 |
 +--- share
       +--- contrib
       +--- man
       +--- tom   // contains predefined mapping
             +--- adt
             +--- c
             +--- caml
             +--- java
```

To install Tom, choose a directory and copy the distribution files there. This directory will be designed in the following by `TOM_HOME`.

JDK 1.5 or newer is required.

14.2.1 Windows

For a painless process, please use the install kit provided. This will automatically update the environment as needed.

Anyway, if for any reason you want to do it all manually, here is the procedure you need to follow:

We assume that Tom is installed in `c:\tom`. The following steps are needed for setting up the environment:

- set environment variable `TOM_HOME=c:\tom`
- add `%TOM_HOME%\bin` to your PATH variable
- check that `JAVA_HOME` is correctly defined, and that `%JAVA_HOME%\bin` is in your PATH variable

For a detailed description of setting environment variables in Windows, please refer to Windows documentation. For Windows XP, some information can be found here:
http://support.microsoft.com/default.aspx?scid=kb;en-us;310519&sd=tech

14.2.2 Windows with Cygwin

If you installed Tom using the install kit, the installation is complete. If you want to install it manually (not recommended), please use the following instructions.

We assume that Tom is installed in `c:\tom\`. Please issue the following for setting up Tom:

```
export TOM_HOME=/cygdrive/c/tom
export PATH=${PATH}:${TOM_HOME}/bin
```

We also suggest you to define a `TOM_LIB` variable and update your `CLASSPATH` accordingly:

```
for i in "${TOM_HOME}"/lib/runtime/*.jar
do
  TOM_LIB="$TOM_LIB:$i"
done
export CLASSPATH=${TOM_LIB}:${CLASSPATH}
```

Note: we recommend to add current directory `.` in your `CLASSPATH`.

14.2.3 Unix

Assuming Tom is installed in `/usr/local/tom`. The following sets up the environment:

```
(bash)
  export TOM_HOME=/usr/local/tom
  export PATH=${PATH}:${TOM_HOME}/bin

(csh)
  setenv TOM_HOME /usr/local/tom
  set path=( $path ${TOM_HOME}/bin )
```

We also suggest you to define a `TOM_LIB` variable and update your `CLASSPATH` accordingly:

```
(bash)
  for i in "${TOM_HOME}"/lib/runtime/*.jar
  do
    TOM_LIB="$TOM_LIB:$i"
  done
  export CLASSPATH=${TOM_LIB}:${CLASSPATH}

(csh)
  set TOM_LIB=‘echo ${TOM_HOME}/lib/runtime/*.jar | tr ’ ’ ’:’‘
  setenv CLASSPATH ${TOM_LIB}:${CLASSPATH}
```

Note: we recommend to add current directory `.` in your `CLASSPATH`.

14.2.4 Eclipse plugin

The Tom eclipse plugin is available directly from the Eclipse platform via the update link:
http://tom.loria.fr/plugin.php

From the Help menu, choose Help Content and look at the Tom Section. You will find there everything to use Tom in a very simple way.

14.3 Getting some examples

Many examples have been written to test or illustrate some particular behaviors. This collection of examples is available at the http://tom.loria.fr/download.php page.

The Tom and Gom compilers are written in Tom itself. The compiler is certainly the most complex program written in Tom. Most of the constructs provided by Tom are used and tested in the project itself.

14.4 Compiling Tom from sources (*)

14.4.1 Getting the sources

The Tom and Gom sources are available through anonymous **cvs(1)**. To get them, use the commands:

```
cvs -d :pserver:anonymous@scm.gforge.inria.fr:/cvsroot/tom login
cvs -d :pserver:anonymous@scm.gforge.inria.fr:/cvsroot/tom checkout -P jtom
```

Developer access is possible via `ssh`. See Gforge for detailed instructions.

The `cvs` checkout will get a new repertory in your current working directory, called `jtom`. We will call this directory `${TOM_BASE}`.

14.4.2 Prepare for the build

First of all, please read `${TOM_BASE}/INSTALL`. Even if the current guide should be enough, this file may contain useful information.

The Tom build process uses apache ant to automate the all parts of the process. This build process is specified by the `${TOM_BASE}/build.xml` file. You will need to install `apache ant` and `Java 1.5` in order to compile Tom.

Note: for Windows, you should include in your PATH variable the `bin` folder of the `apache ant` distribution The build process requires `apache ant 1.7` or more, and a `Java` environment compatible with `Java 1.5`.

Optionally, to customize the build environment, you will have to copy the template configuration file `${TOM_BASE}/local.properties_template` to `${TOM_BASE}/local.properties`, and edit the latter it to reflect your setup. The most common is to set `build.compiler=jikes` to use the `jikes Java` compiler, and `build.compiler.emacs=true` to get errors in a format the `emacs` editor can handle.

14.4.3 Build the Tom distribution

To compile the stable distribution of Tom, you have to use the `${TOM_BASE}/build.sh` script. To use it, first make sure to **cd(1)** to `${TOM_BASE}`. Then you can build the stable distribution.

```
$ ./build.sh stable
```

This creates the `stable` distribution in the directory `${TOM_BASE}/stable/dist`.

To build and install the source distribution, you have to do the following:

```
$ ./build.sh stable
$ ./build.sh src.dist
```

This creates the `src` distribution in the directory `${TOM_BASE}/src/dist`.

To list all the available targets for the build:

```
$ ./build.sh -projecthelp
```

Note: for Windows, just use `build.bat` instead of `build.sh`

14.4.4 Setup

To setup Tom after a source build, you can simply follow the configuration instructions for the binary distribution found in Section 14, using either `${TOM_BASE}/stable/dist` or `${TOM_BASE}/src/dist` for value for the `TOM_HOME` environment variable.

Chapter 15

Using Tom

15.1 The Tom compiler

The Tom compiler is a non-intrusive pattern matching compiler. It takes a Tom program, combination of a host programming language (Java, C or Caml) extended by Tom constructs. Each Tom program can define its own data structures and manipulate them in order to write pattern-matching based algorithms.

15.2 Development process

As mentioned earlier, Tom generates host language code. The command `tom` invokes the compiler on a Tom source file and generates a new source file (with `.java`, `.tom.c`, or `.tom.ml` extension, depending on the compilation command-line). The generated code has to be compiled/interpreted by a tool which can handle the corresponding host language: `javac` for Java, `cc` for C and `ocamlc` for Caml.

A typical development cycle is the following:

- edit a Tom program (by convention, a Tom source code has the `.t` extension)
- run the Tom compiler on this file
- compile the generated file (`javac file.java`, or `cc file.tom.c`,...)
- execute the program (`Java file`, or `a.out`,...)

As `cc` and `javac`, `tom` can compile several input files. By default, the generated files are saved in the same directory as the corresponding input files. When compiling a Java file (i.e. a Tom file where Java is the host language), Tom is smart enough to parse the package definition and generate the pure-Java file in the same package architecture. Similarly to `javac`, `tom` supports a `-d` option which allows the user to indicate where the files have to be generated. To be compatible with `cc` and classical `Makefile`, Tom also supports a `-o` option which can be used to specify the name of the generated file.

Note: Only if a manual installation was performed (without using the kit), Windows users can use the provided shell script `javacForTom.bat` in order to compile the Java files that are generated by Tom. Another script, `javaForTom.bat` can be used to execute the Java bytecode. We recommend the use of these scripts since they update the `CLASSPATH` according to the '*.jar' files that are in the distribution. If you used the install kit, the `CLASSPATH` was updated accordingly at the install time.

15.3 Command line tool

tom [options] filename[.t]

The command takes only one file argument, the name of the input file to be compiled. By convention the input file name is expected to be of the form *filename.t*, whatever the used host language is.

Options:

`--config | -X <file>`	Define an alternate XML configuration file Allow to define the plugins instantiated by the Tom platform
`--cCode | -c`	Generate C code (default is Java) The output file has the extension `.tom.c`
`--camlCode`	Generate Caml code (default is Java)
`--camlSemantics`	Verify with caml semantics for match)
`--compile`	Activate the compiler (by default)
`--csCode`	Generate C# code
`--destdir | -d`	Specify where to place generated files. By default, Tom generates files close to the input file. However (like `javac`), this option allows to specify a directory where generated files have to be put. When compiling a Java file, Tom is smart enough to parse the package definition and generate the pure-Java file in the same package architecture.
`--eclipse`	Activate Eclipse mode
`--encoding <charset> | -e`	Specify the character encoding
`--expand`	Activate the expander (by default)
`--genIntrospector | -gi`	Generate a class that implements Introspector to apply strategies on non visitable terms
`--help | -h`	Show the help Give a brief description of each available options
`--import <path> | -I`	Path to included files Even if inclusion can be performed using relative path, this option specifies list of path where Tom look for when an inclusion has to be done by %include construct
`--inline`	Inline mapping
`--inlineplus`	Force inlining, even if no `$` is used
`--intermediate | -i`	Generate intermediate files The compiler manipulates Abstract Syntax Trees. This option dumps the AST after each phase (parsing, checking, expansion, compilation) This option is useful to analyze the compilation process
`--jCode | -j`	Generate Java code (by default)
`--lazyType | -l`	Use universal type This option makes Tom using a less restrictive backend. In Java, the universal sort `Object` is used more often. This reduces static typing but allows to manipulate inherited data-structures
`--noDeclaration | -D`	Do not generate code for declarations Avoid multiple declaration of symbols when structures are inherited or when multiple inclusion of common data structures are performed
`--noOutput`	Do not generate code No output file is generated. It allows to see warnings and errors without generating the result
`--noReduce`	Do not simplify extracted constraints (depends on –verify)
`--noStatic`	Generate non static functions
`--noSyntaxCheck`	Do not perform syntax checking
`--noTypeCheck`	Do not perform type checking
`--optimize | -O`	Optimize generated code Add an optimization phase to the compilation process. This removes unused variables and performs some inlining.

`--optimize2 | -O2`	Further optimize generated code (does not imply `-O`)
`--output | -o`	Set output file name By default, Tom infers the name of the generated file by replacing the initial file extension by `.java`, `.tom.c` or `.tom.ml`, depending on the chosen target language. This option allows to explicitly give the name of the generated file.
`--pCode`	Generate Python code
`--parse`	Activate the parser (by default)
`--pretty | -p`	Generate readable code with indentation By default, the generated code is synchronized with the source code. This simplifies error reporting but makes the code more difficult to read. This option beautifies the generated code.
`--prettyPIL | -pil`	Prettyprint the intermediate language
`--protected`	Generate protected functions In Java, this option forces the generation of protected functions, instead of private ones, for symbol manipulation functions
`--type`	Typer (activated by default)
`--verbose | -v`	Set verbose mode on Give duration information about each compilation passes
`--verify`	Verify correctness of match compilation
`--version | -V`	Print the version of Tom
`--wall`	Print all warnings Useful in debugging phase

15.4 Ant task

Tom provides an ant task for running the Tom compiler within the apache ant build system.

The Tom ant task is very close in use to the `javac` ant task. Since this task is not part of the official ant tasks, you have first to declare this task in your buildfile, in order to use it.

This is done by the following code:

```
<taskdef name="tom" classname="tom.engine.tools.ant.TomTask">
  <classpath refid="tom.classpath"/>
</taskdef>
```

where `tom.classpath` is the path reference containing all the jar's in Tom's distribution predefined in the file `${TOM_HOME}/lib/tom-common.xml`.

This task is used to produce Java code from Tom programs. A typical use of the Tom ant task is:

```
<tom config="${tom.configfile}"
     srcdir="${src.dir}"
     destdir="${gen.dir}"
     options="-I ${mapping.dir}">
  <include name="**/*.t"/>
</tom>
```

Here, we want to compile all Tom source files in `{src.dir}`, having the generated code in `{gen.dir}`, and we configure the compiler to use the `{tom.configfile}` config file, and pass the options we want like, for example `{-I}` to indicate the mapping needed for compilation, just as we do for Tom in command line.

Another use of this task is:

```
<tom config="${tom.configfile}"
     srcdir="${src.dir}"
     outputfile="${gen.dir}/Example.java"
     options="-I ${mapping.dir}">
  <include name="**/Example.t"/>
</tom>
```

Here we compile only one Tom file, and specify directly the output file name we want to use.

The main usecases for the Tom ant task can be found in Tom's own buildfile.

The Tom ant task takes the following arguments:

Attribute	**Description**	**Required**
classpath	The classpath to use, given as a reference to a path defined elsewhere. This variable is **not** used currently.	No
config	Location of the Tom configuration file.	No
destdir	Location of the `Java` files.	No
failonerror	Indicates whether the build will continue even if there are compilation errors; defaults to `true`	No
logfile	Which log file to use.	No
nowarn	Asks the compiler not to report all warnings; defaults to `no`	No
optimize	Indicates whether source should be compiled with optimization; defaults to `off`	No
options	Custom options to pass to the Tom compiler	No
outputfile	Destination file to compile the source. This require to have only one source file.	No
pretty	Asks the compiler to generate more human readable code; defaults to `no`	No
srcdir	Location of the Tom files.	Yes, unless nested `<src>` elements are present
verbose	Asks the compiler for verbose output; defaults to `no`	No

Chapter 16

Using Gom

16.1 Command line tool

People interested in using Gom as a standalone tool can use the Gom command line interface.

gom [options] filename [... filename]

Options:

`--config <file> | -X`	Defines an alternate XML configuration file
`--debug | -vv`	Display debugging info
`--destdir <dir> | -d`	Specify where to place generated files
`--generator <type> | -g`	Select Generator. Possible value: "shared"
`--help | -h`	Show this help
`--import <path> | -I`	Path for include
`--inlineplus`	Make inlining active
`--intermediate | -i`	Generate intermediate files
`--intermediateName <intermediateName> | -iname`	specify the prefix of intermediate files
`--multithread | -mt`	Generate code compatible with multi-threading
`--optimize | -O`	Optimize generated code
`--optimize2 | -O2`	Optimize generated code
`--package <packageName> | -p`	Specify package name (optional)
`--strategies-mapping | -sm`	Generate tom mapping for strategies
`--termgraph | -tg`	Extend the signature for term-graphs
`--termpointer | -tp`	Extend the signature for term pointers
`--verbose | -v`	Display compilation information
`--verbosedebug | -vvv`	Display even more debugging info
`--version | -V`	Print version
`--wall | -W`	Print warning

16.2 Ant task

Gom can also be used within ant, and has its own ant tasks.

To use the Gom ant task, you have to first declare it the same way as the Tom ant task.

```
<taskdef name="gom"
         classname="tom.gom.tools.ant.GomTask"
         classpathref="tom.classpath"/>
```

Once the task is defined, you can use them to compile a Gom file.

The Gom ant task has to be able to find a configuration file for Gom. It can either use the `tom.home` property to find its configuration file, or use the value of the `config` attribute. Since the `tom.home` property is also used when Gom has to process hooks, it is a good practice to always define the `tom.home` property to the installation path of the Tom system.

The default configuration file for Gom is included in the Tom distribution as `Gom.xml`.

```
<gom config="${gom.configfile}"
     srcdir="${src.dir}"
     package="example"
     destdir="${gen.dir}">
  <include name="**/*.gom"/>
</gom>
```

Like in Tom example, in this Gom ant task we want to compile all Gom source files in `{src.dir}` and to configure the compiler to create a package called `example` in `{gen.dir}` for the generated code, just as we do for Gom in command line.

The Gom task takes the following arguments:

Attribute	Description	Required
config	Location of the Gom configuration file.	No
destdir	Location of the generated files.	No
options	Custom options to pass to the Gom compiler.	No
package	Package for the generated Java files.	No
srcdir	Location of the Gom files	Yes, unless nested `<src>` elements are present

The set of `.gom` files to compile is specified with a nested `include` element.

16.3 Gom Antlr adaptor

GomAntlrAdaptor is a tool that takes a Gom signature and generates an adaptor for a given Antlr grammar file. This way, Gom constructors can be directly used in the rewrite rule mechanism offered by Antlr (version 3). See `examples/parser` the see an example that shows how to combine Tom, Gom and Antlr.

16.3.1 Command line tool

gomantlradaptor [options] filename [... filename]

Options:

`--config <file> | -X`	Defines an alternate XML configuration file
`--debug | -vv`	Display debugging info
`--destdir <dir> | -d`	Specify where to place generated files
`--grammar <grammarName> | -g`	Antlr grammar name
`--help | -h`	Show this help
`--import <path> | -I`	Path for include
`--intermediate | -i`	Generate intermediate files
`--intermediateName <intermediateName> | -iname`	specify the prefix of intermediate files
`--package <packageName> | -p`	Specify package name (optional)
`--termgraph | -tg`	Extend the signature for term-graphs
`--termpointer | -tp`	Extend the signature for term pointers
`--verbose | -v`	Display compilation information
`--verbosedebug | -vvv`	Display even more debugging info
`--version | -V`	Print version
`--wall | -W`	Print warning

16.3.2 Ant task

The GomAntlrAdaptor task takes the following arguments:

Attribute	Description	Required
config	Location of the GomAntlrAdaptor configuration file.	No
destdir	Location of the generated files.	No
grammar	Name of the grammar.	Yes
options	Custom options to pass to the Gom compiler.	No
package	Package for the generated Java files.	No
srcdir	Location of the GomAntlrAdaptor files	Yes, unless nested `<src>` elements are present

Chapter 17

Configuring your environment

17.1 Editor

17.1.1 Vim

The Tom distribution contains some filetype plugins for Tom and Gom support in Vim. They are located in `${TOM_HOME}/share/contrib/vim`.

To install them, you should put the content of the `contrib/vim` directory in `${HOME}/.vim/`. Then in order for these plugins to be automatically used whenever it is necessary, you can put in your `${HOME}/.vimrc`:

```
" indentation depends on the filetype
filetype indent on
filetype plugin on
```

Also, to have vim automatically loading Tom and Gom plugins when editing Tom and Gom files, you can edit (or create) the file `${HOME}/.vim/filetype.vim`:

```
if exists("did_load_filetypes")
  finish
endif
augroup filetypedetect
  au! BufNewFile,BufRead *.t   setfiletype tom
  au! BufNewFile,BufRead *.tom setfiletype tom
  au! BufNewFile,BufRead *.gom setfiletype gom
augroup END
```

For Tom developers, the preferred setup for indenting Tom and Java code is as follows, to be placed in `${HOME}/.vimrc`:

```
autocmd FileType ant   set expandtab
autocmd FileType ant   set sw=2

" automatically indent tom and java code
autocmd FileType java,tom,gom set cindent autoindent
autocmd FileType java,tom,gom set encoding=utf-8
autocmd FileType java,tom,gom set fileencoding=utf-8

" how to indent: in java and tom, 2 spaces, no tabs
autocmd FileType java,tom,gom set expandtab
autocmd FileType java,tom,gom set sw=2
autocmd FileType java,tom,gom set tabstop=2
autocmd FileType java,tom,gom set nosmarttab
```

Note: if the required vim directory and files do not exist, so it is needed to create a folder `${HOME}/.vim` and to copy the standard startup file `${VIMRUNTIME}/vimrc_example` to `${HOME}/.vimrc` before to configure your environment. More information can be found here: http://macvim.org/OSX/index.php

Compiling Tom under Vim

To compile Tom programs (like Tom) under Vim, and get a correct error reporting, you will have to set the `${CLASSPATH}` environment value to the path of `junit.jar`, and use the `makeprg` variable to have `:make` call ant through a script maintaining the link between Tom and the generated Java files. We suppose here that Tom was installed in `${HOME}`, i.e. `${TOM_HOME}` is `${HOME}/workspace/jtom`.

```
let $CLASSPATH = "${HOME}/workspace/jtom/src/lib/tools/junit.jar"
set makeprg=ant\ -find\ build.xml\ -emacs\ $*\\\|\
            \ awk\ -f\ \"${HOME}/workspace/jtom/utils/ant-tom.awk\"
```

17.2 Shell

17.2.1 Zsh

Zsh completion functions for Tom and Gom are available in the `share/contrib/zsh` directory. To install them, you only have to add those files to zsh's `fpath` variable.

For example, assuming you already set up the `${TOM_HOME}` environment variable to the Tom installation directory, you can add to your `${HOME}/.zshrc`:

```
fpath=(${TOM_HOME} $fpath)
```

17.3 Build Tom projects using Ant

To build complex projects using Tom, it is useful to use Ant as build system, to manage generation of data structure using Gom and the compilation of Tom and Java code.

To ease the use of Ant, the file `${TOM_HOME}/lib/tom-common.xml` is provided in the Tom distribution. This file provide initialization for Tom and Gom Ant tasks. To load `tom-common.xml`, you just have to put in your Ant script:

```
<property environment="env"/>
<property name="tom.home" value="${env.TOM_HOME}"/>
<import file="${tom.home}/lib/tom-common.xml"/>
```

Then, each target depending on the `tom.init` task will allow the use of the Gom and Tom ant tasks, as well as `tom.preset` and `javac.preset`, providing usual values for the attributes of those tasks. Also, `tom-common.xml` provides several properties, as `tomconfigfile` and `gomconfigfile`, providing the location of the configuration files for Tom and Gom, and `tom.classpath`, containing all classes related to the Tom installation.

For example, if you have a directory called `tom_example` with Tom source files and Gom source files which generate the Tom mapping required by `tom_example`, you can create the following Ant script to compile all Gom, Tom and Java code.:

```
<?xml version="1.0" encoding="ISO-8859-1"?>
<project name="Example Ant for TOM" basedir="." default="compile">
  <description>
    A simple example of build script using Ant offering compilation of TOM programs.
  </description>

  <!-- Initializing Tom and Gom -->
  <property environment="env"/>
  <property name="tom.home" value="${env.TOM_HOME}"/>
```

```
  <import file="${tom.home}/lib/tom-common.xml"/>

  <!-- Defining folders -->
  <property name="my_example" value="tom_example"/>
  <property name="src.dir" value="."/>
  <property name="gen.dir" value="gen"/>
  <property name="build.dir" value="build"/>
  <property name="mapping.dir" value="${gen.dir}/${my_example}/${my_example}"/>

  <!-- Declaring Tom task -->
  <taskdef name="tom" classname="tom.engine.tools.ant.TomTask">
    <classpath refid="tom.classpath"/>
  </taskdef>

  <!-- Declaring Gom task -->
  <taskdef name="gom"
           classname="tom.gom.tools.ant.GomTask"
           classpathref="tom.classpath"/>

  <target name="init" depends="tom.init" description="To realize initialization">
    <mkdir dir="${gen.dir}"/>
    <mkdir dir="${build.dir}"/>
  </target>

  <target name="compile" depends="init" description="To compile all programs">
    <!-- Compiling Gom programs -->
    <gom config="${gomconfigfile}"
         srcdir="${src.dir}"
         package="${my_example}"
         destdir="${gen.dir}">
      <include name="**/*.gom"/>
    </gom>

    <!-- Compiling Tom programs -->
    <tom config="${tomconfigfile}"
         srcdir="${src.dir}"
         destdir="${gen.dir}"
         options="-I ${mapping.dir}">
      <include name="**/*.t"/>
    </tom>

    <!-- Compiling Java programs -->
    <javac srcdir="${gen.dir}" destdir="${build.dir}">
      <classpath path="${build.dir}"/>
      <include name="**/*.java"/>
    </javac>
  </target>

  <target name="clean" description="To remove generated code">
    <delete dir="${gen.dir}"/>
    <delete dir="${build.dir}"/>
  </target>
</project>
```

Chapter 18

Migration Guide

This chapter documents important changes in the Tom language that impact running code. We explain how to modify your programs in order to be able to use the last version of Tom.

18.1 Migration from 2.5 to 2.6

Tom

- the mapping can now be inlined. To activate this option (`--inline` and `--inlineplus`), the parameters of a mapping have to be prefixed by a '`$`'
- the antlrmapped has been removed and replaced by the GomAntlrAdapter, see Section 16.3.
- when defining a mapping, is no `make` is defined, a default one (corresponding to a function call) is automatically added. Since version 2.6, it is added only if no other mapping construct is defined.

Gom

- the Java code generated for list-operators is now implementing the Collection interface. Therefore, the name `Empty` can non longer be used for a constructor, this would generate two `isEmpty()` methods.

Strategies

- the forward mechanism is no longer used. Hand written strategies have to be modified as explained in 12.8.
- `mustrategy.tom`, `mutraveler.tom`, and `strategy.tom` have been removed. `sl.tom` has to be used instead.

18.2 Migration from 2.4 to 2.5

Gom

Representation of lists (FL). The default behaviour of lists is FL. The semantics has changed in case of associative symbol under an other associative symbol.

Gom syntax. The syntax compatibility with Vas is now not available.

Tom

The `%rule` has been removed. It can be replaced by `rules` hooks in Gom, described in Section 11.2. The syntax for rules is unchanged, except that '`where`' clauses are no more supported. Since rules are integrated into the code generated by Gom, it is no more possible to short-circuit rule application by calling Java functions instead of '`‘`' to built terms.

Strategies

`%include { mustrategy.tom }` should be replace by `%include { sl.tom }`

Any reference to `jjtraveler` or `tom.library.strategy.mutraveler` should be replaced by a reference to `tom.library.sl`:

- replace `import tom.library.strategy.mutraveler.*;` by `import tom.library.sl.*;`
- replace `import jjtraveler.*;` by `import tom.library.sl.*;`
- replace `jjtraveler.Visitable` by `tom.library.sl.Visitable`
- replace `jjtraveler.VisitFailure` by `tom.library.sl.VisitFailure`
- replace `jjtraveler.Visitor` by `tom.library.sl.Strategy`
- replace `jjtraveler.reflective.VisitableVisitor` by `tom.library.sl.Strategy`
- replace `MuStrategy` by `Strategy`

`getPosition()` should be replaced by `getEnvironment().getPosition()`
`apply(...)` should be replaced by `visit(...)` or `visitLight(...)`, enclosed by a `try ... catch(VisitFailure e)`
Call to `MuTraveler.init` should be removed
The backquote for the default strategy in `%strategy` could be removed.

18.3 Migration from 2.3 to 2.4

Builtins

Since version 2.4, builtin sorts (int, long, String, etc.) are no longer implicit. The corresponding `%include { ... }` must be done explicitly.

Gom, Vas, and ApiGen

Since version 2.4, ApiGen and Vas are obsolete. Gom should be used instead.

18.4 Migration from 2.2 to 2.3

Mapping definition and term notation

To avoid ambiguities, since version 2.3, constants should be written using explicit parentheses: `a()`, `nil()`, for example. To be coherent, the parentheses have also to be used in the mapping definition:

```
%op T a() {
  ...
}
```

Static functions

Since version 2.3, Tom generate static functions in Java, instead of object methods. This allows to use Tom constructs in the `main()` function, this improves the efficiency of the generated code, and this makes safer the use of strategies.

To be compatible with the previous version, the `--noStatic` flag can be used.

From Vas to Gom

In the future, Gom will replace Vas. To make the migration easier, the Gom compiler accepts the Vas syntax. However, there are some minor changes:

- in Gom the importation of builtin modules (`int`, `String`,...) should be explicit,
- when using the new ML-like syntax, the defined sorts should no longer be declared,
- factories are no longer needed by the generated code. As a consequence, `Java` imports and constructors are simpler,
- the methods to get and set values of subterms are named after the slot name: for a slot named `slot` of type `SlotType`, the access and modification are `getslot()` and `setslot(SlotName value)`. The `String getName()` function is now `String symbolName()`, and there is no more `int getArity()`.
- The methods `boolean isOperator()` now use the exact name of the operator, without capitalizing it.
- when defining a list-operator, Gom automatically generates `Java` access functions. `getHead`, `getTail`, and `isEmpty` are replaced respectively by `getHeadconc`, `getTailconc`, and `isEmptyconc` for a list-operator named `conc`.
- objects generated by Gom do no longer implement the ATerm interface. Therefore, some functionalities have disappear. In particular, `genericCollect` and `genericTraversal` can no longer be used. The strategy language has to be used instead.
- to implement strategies on a module `Module`, the class `ModuleBasicStrategy` replaces the `ModuleVisitableFwd` of Vas.

18.5 Migration from 2.1 to 2.2

Mapping definition

Since version 2.2, the mapping definition formalism has been simplified. Therefore, we are no longer able to be fully compatible with the old syntax. Some small and simple modifications have to be performed:

- in `%op`, the slot-names are no longer optional. For each argument of a constructor, a name has to be given. This name can then be used within the "bracket" notation.

  `%op T f(T,T)` has to be replaced by `%op T f(arg1:T,arg2:T)`, where `arg1` and `arg2` are slot-names.

- for each slot-name, a `get_slot(name,t)` construct has to be specified. This defines, given an object `t`, how to access to the slot-name named `name`.

  The definition of `get_slot` can be defined by using the previously defined construct `get_subterm` (the first slot corresponds to the $0-th$ subterm, second slot to the $1-st$ subterm, *etc.*). Thus, for the previous example, we can have:

```
%op T f(arg1:T, arg2:T) {
  get_slot(arg1,t) { get_subterm(t,0) }
  get_slot(arg2,t) { get_subterm(t,1) }
}
```

- for each operator (`%op`, `%oplist`, and %oparray), the `is_fsym(t)` predicate has to be defined. This function should return `true` when `t` is rooted by the considered symbol, and `false` otherwise. In practice, the constructs can be deduced by combining `get_fun_sym`, `cmp_fun_sym`, and `fsym`:

```
%op T f(arg1:T, arg2:T) {
  is_fsym(t) { cmp_fun_sym(get_fun_sym(t), body of the old fsym construct) }
  get_slot(arg1,t) { get_subterm(t,0) }
  get_slot(arg2,t) { get_subterm(t,1) }
}
```

- in `%oplist`, get_head, `get_tail`, and `is_empty` have to be defined. In practice, these definitions have to be copied from `%typelist` to `%oplist`
- in `%oparray`, get_element, and `get_size` have to be defined. In practice, these definitions have to be copied from `%typearray` to `%oparray`
- `%typelist`, and `%typearray` do no longer exist: `%typeterm` has to be used to define any kind of sort. This is not a problem since access functions are now defined inside operator definitions (`%op`, `%oplist`, or `%oparray`)
- `get_fun_sym`, `cmp_fun_sym`, and `get_subterm` do no longer exist in `%typeterm`
- `fsym` do no longer exists in `%op`, `%oplist`, and `%oparray`

As an example, let us consider the following "old" mapping definition:

```
%typeterm TomTerm {
  implement          { ATermAppl        }
  cmp_fun_sym(t1,t2) { t1 == t2         }
  get_fun_sym(t)     { t.getName()      }
  get_subterm(t, n)  { t.getArgument(n) }
  equals(t1, t2)     { t1 == t2         }
}

%typelist TomList {
  implement          { ATermList               }
  get_fun_sym(t)     { ((t instanceof ATermList)?"conc":null) }
  cmp_fun_sym(t1,t2) { t1 == t2                }
  equals(l1,l2)      { l1 == l2                }
  get_head(l)        { (ATermAppl)l.getFirst() }
  get_tail(l)        { l.getNext()             }
  is_empty(l)        { l.isEmpty()             }
}

%op TomTerm a {
  fsym   { "a" }
  make() { factory.makeAppl(factory.makeAFun("a", 0, false)) }
}

%op TomTerm f(TomTerm) {
  fsym     { "f" }
  make(t1) { factory.makeAppl(factory.makeAFun("f", 1, false),t1) }
}

%oplist TomList conc( TomTerm* ) {
  fsym             { "conc"             }
  make_empty()     { factory.makeList() }
  make_insert(e,l) { l.insert(e)        }
}
```

The two first type definitions have to be replaced by:

```
%typeterm TomTerm {
  implement      { ATermAppl }
  equals(t1, t2) { t1 == t2  }
}

%typeterm TomList {
  implement     { ATermList }
  equals(l1,l2) { l1 == l2  }
}
```

The operator definition can be replaced by the following code:

```
%op TomTerm a {
  is_fsym(t) { t.getName() == "a" }
  make()     { factory.makeAppl(factory.makeAFun("a", 0, false)) }
}

%op TomTerm f(arg:TomTerm) {
  is_fsym(t)      { t.getName() == "f" }
  get_slot(arg,t) { (TomTerm) t.getArgument(t,0) }
  make(t1)        { factory.makeAppl(factory.makeAFun("f", 1, false),t1) }
}

%oplist TomList conc( TomTerm* ) {
  is_fsym(t)       { t instanceof ATermList }
  get_head(l)      { (ATermAppl)l.getFirst() }
  get_tail(l)      { l.getNext() }
  is_empty(l)      { l.isEmpty() }
  make_empty()     { factory.makeList() }
  make_insert(e,l) { l.insert(e) }
}
```

Disjunction of patterns

Since version 2.2, the disjunction of patterns construct has become deprecated. It can still be used, but we recommend to use the disjunction of symbols instead. This last construct allows to share patterns which have similar subterms but different head-symbols. Therefore, the construct `g(g(a)) | g(h(a))` can be replaced by `g( (g | h)(a) )`. Since version 2.2, this construct has been extended to support disjunction of symbols which do not have identical signature: only involved slots have to be compatible.

Considering `%op T f(arg1:T, arg2:T)` and `%op T g(arg1:T)`, it is now possible to write `g( (g | f)[arg1=a] )`.

Variable

To prepare a future extension where variables have to be distinguished from constructors of arity 0, we have turned into error all ambiguities between variables and constructors. As a consequence, a variable cannot any longer have the same name as a constant.

Vas

Since version 2.2, ApiGen and Vas have been updated:

- name of list-operators defined in Vas are now significant and can be used in `match` constructs.
- generated Tom mappings are now stored in the same directory as the generated factory. In practice, imports of the form `%include{ file.tom }` have to be replace by `%include{ package/file.tom }`.

Strategy library

The `TravelerFactory` class has been removed and replaced by a Tom mapping: `mutraveler.tom`. Therefore, backquote notation has to be used: `travelerFactory.Repeat(travelerFactory.OnceBottomUp(rule))` is replaced by `‘Repeat(OnceBottomUp(rule))`.

18.6 Migration from 2.0 to 2.1

Tom library

Since version 2.1, the runtime library has been reorganized. `Java` importations have to be updated according to the following hierarchy:

```
tom
 |--- library
 |        |--- adt               (datatype definitions)
 |        |--- mapping           (predefined mapping)
 |               |--- adt        (generated mapping)
 |        |--- plugin            (platform tools)
 |        |--- set               (to handle sets)
 |        |--- strategy
 |               |--- concurrent (to support parallel strategy)
 |        |--- traversal         (generic traversal)
 |        |--- xml               (xml tools)
 |
 |--- platform                   (the Tom Plugin Platform, known as Tom server)
          |--- adt
```

Command line options

- `--protected` is a new option which makes Tom generates protected access functions. By default, access functions are now private instead of public,
- `--noWarning` has been replaced by its dual `--wall` (for printing warnings).

18.7 Migration from 1.5 to 2.0

New backquote usage

Since version 2.0, Tom integrates an optimizer which removes unused variable assignments and performs inlining optimizations. In order to make these optimizations correct, the Tom compiler needs to know whether a Tom variable (instantiated by pattern matching) is used or not.

In previous versions of Tom, it was possible to use or re-assign a Tom variable without any particular requirement. Since version 2.0, it is recommended (and needed if you want to use the optimizer) to use the backquote mechanism to retrieve the value of a Tom variable. The syntax of a backquote construct has been modified in the following way:

- ‘`Name` (like ‘`x`) is now correct. This allows access to the value of a Tom variable. This construct also allows access to the value of list-variable, but the ‘`Name‘*` construct is to be preferred,
- ‘`Name‘*` (like ‘`X*`) is now correct. This allows access to the value of a Tom list-variable,
- ‘`Name( ... )` is correct, as in previous versions. This construct builds a term in memory,
- ‘`( ... )` is now correct and can be used to simulate the previous syntax. Since version 2.0, it is no longer possible to start a backquote construct by using something different from a `Name` or a ‘`(`’. Thus, ‘`1+x` is no longer valid: ‘`(1+x)` or `1+‘x` has to be used instead,
- ‘`xml( ... )` has to be used to create an XML term.

Command line options

- `--destdir` (short version: `-d`) option: as in `javac`, this option specify where to place generated files,
- `--output` (short version: `-o`) option: as in `gcc`, this option specify the name of the *unique* generated file. This option is not compatible with `--destdir`,
- `-o` is no longer the short version of `--noOutput`.

Predefined mapping

Since version 2.0, Tom does no longer support predefined builtin sorts, via `%typeint`, `%typestring` or `%typedouble`. Tom comes now with a library of predefined mappings. Among them, `int.tom`, `string.tom` and `double.tom`. In order to use these mappings, the `%include` construct should be used (i.e. `%include{ int.tom }` to import the predefined `int` mapping).