FMS: Functional Programming as a Modelling Language

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Abstract. In this paper we introduce the Functional Modelling System (FMS). The system introduces the Functional Modelling Language (FML), which is a modelling language for NP-complete search problems based on concepts of functional programming. Internally, we translate FML specifications to an Answer Set Program to obtain models. We give a general overview of the new FML language, and how this language is handled in the system. We give a step-by-step walkthrough of the system, pointing out what features are in place, and what improvements are still possible.

1 Introduction

We have published a theoretical framework in which we explain how lambda calculus could be used to define higher order logics[4]. Based on these ideas we now present a practical Functional Modelling System (FMS), powered under the hood by an Answer Set Programming (ASP) solver. The system is focused on solving NP-complete search problems, the same class of problems its underlying engine - ASP - can solve. In this paper we give a high level overview of the system, point out which techniques and algorithms are already implemented and highlight the places where there is low-hanging fruit for improving the system. In Section 2 we give an overview of the language of the system, both on the external and the internal level. In Section 3 we explain what steps a file goes through to produce an answer. In Section 4 we take a deeper look into what kind of optimisation techniques are present in the system. We conclude in Section 5 with information on the tooling and availability of the system.

1.1 Context

In this paper we use the concept of modelling language to denote a language which is used to express a set of rules to which solutions should adhere. Typically, modelling languages allow for naturally expressing NP-complete problems. A solution for this set of rules is called a model. Typical examples of such languages are Minizinc[12], ASP[15] and FO(,)[2], the language of IDP3. The new Functional Modelling Language (FML) is an addition to this set of modelling
languages. Most previous systems have their roots in logic programming, and first order logic. The new FML language is based on constructs which are traditionally only found in functional programming languages. With these constructs it is still possible to use traditional first order logic specifications, but there are also new modelling possibilities.

The only other fully higher order modelling language that the authors are aware of is ProB[9]. The expressive power of ProB is very high but the solving capabilities of this language are limited. The system is mainly used to model dynamic systems and not to solve search problems.

Monadiccp[16] and ersatz are Haskell libraries, through which it is also possible to define search problems using a functional language. It allows the user to define constraint satisfaction problems using Haskell, which is then translated to respectively a constraint programming or a SAT solver. While the host language is a fully higher-order language, the problems that can be specified in monadiccp are only first order. Ersatz does have the notion of relations, but somebody writing the specification has to think about the possible range of values while declaring the relation. FMS takes this one step further as the domain of the function is derived from the specification.

1.2 Search Technologies

There are a multitude of existing technologies apt for solving search problems. SAT solvers have become very efficient and are the standard for a number of problems, but there are also a lot of other technologies: SMT (SAT modulo theories) which extends SAT with higher level concepts, constraint programming systems, mixed integer programming, .... FMS does not contribute to these search technologies, but to the modelling techniques for these.

For FMS, ASP was chosen. ASP solvers use a SAT solver with some extensions for recursive logic definitions. ASP was chosen because the language itself is already relatively high level, so it is easier to build another language on top of ASP compared to other paradigms such as SAT.

1.3 First Order or Higher Order?

FML supports higher order expressions: functions which take functions as input and return new functions. Higher order sets are also supported: it is possible to define \( s \) as the set \( \{\{1, 4\}, \{1, 6, 7\}, \{5, 4, 9\}\} \).

We have a polynomial translation to ASP which has first order semantics, from this it follows that the semantics of our language is not higher order. The higher order aspects of the FML language are syntactical sugar for a first order encoding of higher order functionality.

Nevertheless, this approach allows for modelling techniques which were not possible before in modelling languages. For instance in Listing 1 you can see an FML specification which declares the constants \( c \) and \( d \) as numbers between 3 and 5. The next line defines the set \( s \) as the set containing the doubling function,
the function which adds \( c \) to a number and the function which multiplies a number by \( c \). The last line starts with \(!\) which means “forall”. So the line means: for every function \( f \) in the set \( s \), \( f \) applied to \( d \) is smaller than \( 10 \). There is exactly one model for this, which maps both \( c \) and \( d \) to \( 3 \).

### 1.4 Advantages

There are a number of advantages when comparing FML to existing modelling languages. One driving factor for higher order language is the easy abstraction of concepts. Suppose that you want to want to find 2 different solutions of the N-queens problem so that no two queens occur in the same place. In traditional ASP or MiniZinc (a constraint programming language), one would need to write down the N-queens constraints twice: once for each of the two solutions. Extensions for ASP have been introduced to introduce templates\([6]\), which circumvent this problem but make a fundamental difference between first order and higher order predicates. FML does not require the user to differentiate between first and higher order terms and allows to easily reuse the higher order predicate \( \text{nqueens} \) indicating that \( \text{solution} \) is a solution to the \( \text{nqueens} \) problem. The FMS modelling for this problem can be seen in Listing 2.

A second advantage of the FML is the propagation of the domains. In most traditional modelling languages, whenever you declare a function or predicate, you need to specify a finite domain. This would disallow a definition of prime numbers as short as “\( \text{prime} \ x \ := \ ! \ (\{2..x\-1\} \ (y \ -> \ x \ % \ y > 0)) \)” (\( x \) is prime if for all numbers \( y \) between 2 and \( x \)-1, \( x \) modulo \( y \) is larger than 0) because this is a function with an infinite domain (all integers). FML allows this by automatically deriving the relevant domain of the function from the constraints.
Listing 2 Find 2 N-queen solutions which have no shared queens

domain := {1..8}.
solution1/1 :: function to domain.
solution2/1 :: function to domain.

alldiff solution f := ! domain (\x ->
  ! domain (\y -> x ~= y => f x ~= f y)).

nqueens solution := ! {
  solution,
  \x -> x - solution x,
  \x -> x + solution x
}(alldiff solution).

nqueens solution1.
nqueens solution2.
! domain (\x -> solution1 x ~= solution2 x).

2.1 Core Language

FML is based on the lambda calculus. This lambda calculus is extended with
some common constructs (such as let-bindings and numbers) and less common
constructs (such as the built-in notion of a set). There are ten language constructs
in the Core language. Nine with a semantic meaning, and one to track the values
which are needed in the output. This language does not have an explicit syntax
as it corresponds to the internal representation of the language. However, it can
be useful to see an approximate BNF for this Core language which can be seen
in Listing 3. The language constructs you can see in the BNF are:

- **Variable** A traditional reference to a bound identifier
- **Application** This construct applies a function to an argument.
- **Lambda** Internally, this is the only way a function can be declared. Lambdas
  abstract away one single variable. If multiple arguments are required, this
  language construct should be nested. Note that a tuple counts as a single
  argument.
- **Let binding** Introduces some local definitions in a new expression. A binding
  binds a variable to an expression, possibly recursively. This is the only way
  to bind a term recursively.
- **Injection** This is a way to inject an arbitrary JVM object into the language.
  In the current system, it is only used to inject integers and strings. In the
  future this construct could be used to reason over arbitrary JVM objects.
- **Case** This language construct handles all pattern matching. This can be seen
  as a generalised form of an if-then-else construct. An if-then-else construct
  would only handle patterns: true and false.
- **Builtin symbol** There is quite a list of built-in functions for the FMS. The
  reason for this is not always that we can’t define them in the language,
but that they are common functions and a dedicated method for translating them leads to a more efficient translation to ASP. Builtin functions include arithmetic operations (+,*), boolean functions (&,|) and set functions (forall: !, exists: ?).

**Set Expression** Sets could be emulated through the use of constructors but for efficiency reasons we opted to have sets as an explicit built-in datatype of the language. This language construct makes a finite set containing some expressions. The type system enforces that all elements of a set are of the same type. To represent all set expressions contained in the Full language, this Core construct needs to be combined with some builtin symbols.

**Herbrand Expression** This construct corresponds to the declared constructors. It is a named constructor optionally applied to some arguments. These constructors can be pattern matched using the Case construct.

**Output Expression** This language construct is the only one which says nothing about the actual meaning of the expression but is a construct to annotate that the expression it contains should be outputted using a certain name. 4 + outputExp("a", 5) would denote an expression that evaluates to 9, but the subexpression 5 should be outputted under the name "a". Most languages use some kind of print statements for this. But as we don’t have those in a modelling language like FML, we have to track the values we want to print in another way.

**Types** FML is strongly typed, this means that every expression has a type which is enforced at compile time, before trying to run the program. The language is also implicitly typed, this means that these strong types are not necessary parts of the syntax and it is possible that the input file contains no type annotations.

The type system itself is a Hindley-Milner type system, which includes polymorphism through universal quantification over types. E.g. The forall quantifier
 Constructors It is possible to declare new constructors and deconstruct values which are made of these constructors using the case-construct. An example using peano arithmetic is shown in Listing 4.

2.2 Full Language

The Full language extends the Core language with a lot of syntactic sugar. The process of converting the Full language to the Core language is called desugaring. We will take the graph coloring problem as a leading example throughout this section. The formulation of a graph coloring problem in FML can be seen in Listing 5.

In the Full language, we discern three different kinds of statements: declarations, definitions and constraints. Declarations introduce new symbols for which the interpretation is not given through a definition (e.g. symbol colorof). Definitions introduce new symbols of which the interpretation is fixed (e.g. the border relation). Constraints are boolean expressions which must be true in every model (e.g. adjacent nodes have different colors).

**Declarations** Declarations have the form: \texttt{name :: declarationkind.}. The most important declarations are:

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**Listing 4** Minus One in Peano Arithmetic (in the Full language)

\[
\begin{align*}
s/1 &::\text{constructor}. \\
il/0 &::\text{constructor}. \\
\text{minusOne } x &::= \text{case } x \text{ of} \\
&\text{s [ a ] -> a; } \\
&\text{nil [ ] -> nil;}. \\
\end{align*}
\]

**Listing 5** Graph Coloring (in the Full language)

\[
\begin{align*}
\text{// Definitions of given sets} \\
borders &::= \{("a","b"),\ ("b","c"),\ ("c","a")\}. \\
\text{colors} &::= \{1..3\}. \\
\text{// Declaration of the interpretation we are looking for} \\
\text{colorof/1} &::\text{function to colors.} \\
\text{// Constraint: For all borders } (x,y) \text{ the color of } x \\
\text{should be different than that of } y \\
\text{! borders (}\&(x,y) \text{ -> colorof } x \neq \text{colorof } y\text{).} \\
\end{align*}
\]

has the following type: \(\forall a.\ \text{Set } a \rightarrow (a \rightarrow \text{Bool}) \rightarrow \text{Bool}\). In the implementation itself, the universal quantification is left implicit.

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**Declarations** Declarations have the form: \texttt{name :: declarationkind.}. The most important declarations are:

---
- $e :: \text{element of set}$ where set is an expression evaluating to a set. The interpretation of $e$ will be a single element of the interpretation of the set.

- $s :: \text{subset of set}$ where set is an expression evaluating to a set. The interpretation of $s$ will be a subset of the interpretation of the set.

- $f/\text{arity} :: \text{function to set}$ where set is an expression evaluating to a set and arity a natural number. The interpretation of $f$ will be a function of arity arity with codomain set.

- $c/\text{arity} :: \text{constructor}$ where arity is a natural number. The interpretation of $c$ will be a new constructor function of arity arity.

There are also extra declarations like proposition or predicate. These can be rewritten in terms of other declarations such as element of $\{\text{true}, \text{false}\}$ or function to $\{\text{true}, \text{false}\}$

**Example 1.** A graph coloring problem needs one declaration: the coloring of the nodes, which is a function to colors.

**Definitions/Constraints** A definition has the form identifier := expression. A constraint is just an expression by itself. Definitions can be recursive and mutually dependent (e.g. mutually dependent odd and even definitions). There is built-in support for first order logic connectives, quantifiers, arithmetic and set-expressions. The quantifiers forall (!) and exists (?) are slightly different from the traditional notation in first order logic. They are higher order functions with two arguments: the set they are quantifying over and a boolean function explicating the property which needs to hold.

**Example 2.** A graph coloring problem needs two defined relations: the borders and the colors. These can just be given as a set expression. There is one constraint, which quantifies over all borders. We can deconstruct the tuples in the border-relation in place using $(x,y) \rightarrow \ldots$. The body of the forall quantifier just states that the colors $x$ and $y$ should be different.

**Set Expressions** Set expressions are a language feature based on the set-builder notation of mathematics. The set expressions in the Full language are much more general than those of the Core language. The syntax is heavily inspired by the notation in Haskell and Python. Set expressions can be replaced by a series of map and filter operations on sets but allow for a more readable syntax. Point-wise application of a function $f$ over a set $s$ looks like: $\{f \ x \mid x \gets s\}$. Which can be read as: the set of evaluation of $f$ $x$ where $x$ is in the set $s$. Or the subset of $s$ for which the predicate $p$ holds can be written as: $\{x \mid x \gets s, p\ x\}$.

### 3 General Workflow

A lot of inspiration for the general workflow of FMS came from GHC[17]. FMS can be seen as a compiler to Answer Set Programming and most of the steps in
the compiling process of GHC is relevant to FMS. An overview of the workflow can be seen in Figure 1. In this section we go over these steps to investigate them in more detail, from the file containing an FML specification to the models.

![Figure 1. The general workflow of FMS](image)

### 3.1 Parse and Desugar

Parsing an FML specification is done using the ANTLR4\[13\] system. Based on a BNF grammar, ANTLR4 generates an Abstract Syntax Tree (AST) of an FML specification. This syntax tree is then desugared into the Core language, as defined in Section 2.1. Checking whether any identifiers are used out of scope is considered the last step in the desugaring process. Once a string is fully parsed and desugared, it becomes a self-contained well-formed Core expression without free variables.

*Example 3.* The expression $f \ 1 := 0. \ f \ x := 1$

is desugared to $f := (\ y \rightarrow \ \text{case} \ y \text{ of} \ 1 \rightarrow 0 \ ; \ x \rightarrow 1)$

*Example 4.* The expression $(a,b) := f \ 5$ is desugared to

$\text{temp} := f \ 5$. 
\[ a := \text{case temp of } (a,_) \rightarrow a. \]
\[ b := \text{case temp of } (_,b) \rightarrow b. \]

The reasoning behind this desugaring is that all pattern matching needs to be done in the case-construct and definitions can internally only define a single variable, but the unsugared line defined \( a \) and \( b \) using a single assignment.

Desugaring complex set expressions results in usages of the bind built-in. The bind operation is the same as the bind for monads in Haskell\[18\] sometimes known as flatmap. Flatmap (specialised for sets) boils down to a pointwise application followed by a flattening. Desugaring sets could potentially be further improved by using an applicative style instead of a monadic style wherever possible\[10\]. An applicative style omits the flattening part and can be more efficient, but has less expressivity.

\textit{Example 5.} The flattening of a set \( ss \) can be expressed by the following expression:
\[ \{ x || s <- ss, x <- s \} \]
Which is desugared to: \( \text{bind ss } (\lambda s \rightarrow \text{bind } (\lambda x \rightarrow \{x\})) \)

Our approach directly transforms a FML specification to the Core language, which has some disadvantages. While the location information of symbols is stored inside the Core language data structures, some details about the original representation get lost. This means that every error which is detected in the file after desugaring is less clear than if the analysis would have been done on the original representation. This mainly concerns errors about out-of-scope identifiers and typing errors, these are exactly the ones which are checked on the desugared version in GHC\[17\].

3.2 Optimise

We could directly translate the Core language to ASP. However, there are many specification transformations which make the specification simpler. For this reason a number of optimisation techniques are applied to the expressions in the Core language. These optimisations deserve their own section and are further described in Section 4.

3.3 Type Check

Types have no semantic value in FML. This means that the evaluation of a specification can be done without taking typing information into account. Nevertheless, types are an important tool to detect mistakes in a specification, both for the end-user who writes a specification, and for a compiler writer when implementing optimisations to check that the optimised version of the specification is still well-typed. A fairly standard Hindley-Milner\[14\] type system is implemented on the Core language (and not on the Full language). As explained in Section 3.1, a second implementation on the Full language would improve the error messages produced by the type system. Note that doing type checks on the
Full language does not fully eliminate the need for a type checker at the Core level, type checking on Core is still useful to detect errors in the optimisers. The error diagnosis in case of a badly typed expression is also very vague in the current state of the system. Many extensions of the standard algorithm exist which would lead to clearer error messages[19], a future version of the system would benefit from those.

3.4 Translate

The translation is arguably the most important part of the system. This part of the system does the job of translating the Core language to an Abstract Syntax Tree representation of ASP. Although the algorithm is complex, it is only a minor part of the actual code. The inner workings of the translation process is considered out of scope for this paper, but we give some intuitions using Listing 6, which is the translation of the graph coloring example of Listing 5. ¹ More details about translating a functional language into ASP is given in another paper presented at WFLP 2018.

The ASP programs that FMS produces contain three kinds of statements. Declarations are translated to choice rules. Definitions and constraints are translated to definitions and there is one constraint: it enforces that the evaluation of the constraints is true. This constraint can be seen on line 1. Sets are characterised by a name such as \( s_0 \), and \( \text{member}/2 \) represents the membership relation between sets and their elements. Line 2 in the translation defines the set \( s_0 \) as

1 The translation presented is slightly simplified for readability. The only difference lies in the omission of superfluous empty tuples
Listing 7  An Answer Set of the program in Listing 6

result(b2)
bool((b0,("a","b")))
bool((b0,("b","c")))
bool((b0,("c","a")))
bool(b2)
lamDom(10,"a")
lamDom(10,"b")
lamDom(10,"c")
lamInter(10,"a",1)
lamInter(10,"b",3)

the numbers of 1 to 3. In line 3 you can see that this set represents the set of colors of the input. The `lamInter/3` relation is used to define the relation between a function (the first argument), an input (the second argument) and its output (the third argument). Line 4 defines 10 as an uninterpreted function mapping every member of `lamDom` (the predicate which is used to represent the relevant domain of the function) to a member of the set `s0`. This corresponds to the colorof function, this is explicitated in line 5. Lines 6-9 do the same thing for borders as lines 2-3 did for colors. Lines 10 and 11 define that the relevant domain are the first and second components of the elements in the set of borders. Line 12-15 make up the translation of the constraint. Just like functions, booleans are given a name like `b0`. The `bool/1` relation is used to indicate whether the boolean is considered true. In line 16, it can be seen that the boolean `b2` is considered the top constraint.

As a whole this ASP program has models which correspond to the 6 possible colorings of the graph. One example answer set can be seen in Listing 7. Once the translation is obtained, we send this ASP program further into our workflow towards Clingo.

3.5 Clingo

We chose the ASP solver Clingo as a backend for our system. We communicate with Clingo via text files and use JSON output facilities of Clingo to be able to easily parse the answer sets. From the viewpoint of implementing FMS this is a very easy step. We print the ASP AST to a text file, call Clingo and reparse its output. The advantages of file-based communication are that it is easily debugged as it is human readable and it is easy to replace Clingo with another solver using the ASP Core[3] standard. It would be more efficient to directly use the internal APIs of Clingo to build the ASP program. Clingo produces answer sets, which represent models for the problem, but it is still not the end of our workflow.
3.6 Reinterpreting the Answer Sets

Answer sets map one-to-one to FML models. However, it is not obvious how the answer sets from Clingo relate to the original problem statement, as can be seen in Listing 7. The answer set possibly contains higher order functions and sets, which are relatively complicated when encoded in answer set. This step reorders the information of the answer set into a more natural format.

Example 6. The answer set in Listing 7 is transformed to the following model for the end user:

\[
\{ \text{borders} = [(a,b), (b,c), (c,a)], \\
\text{colorof} = [(a,1), (b,3), (c,2)], \\
\text{colors} = [1, 2, 3] \}
\]

In this step we also notice the consequences of file-based communications with Clingo. In most situations, not all information in the answer set must be presented to the end user. The current approach only lets us filter the information after the solver has finished and printed the complete answer set. A tighter integration with Clingo could overcome this problem.

4 Optimisations

FMS contains a number of optimisations which are transformations of Core expressions. Optimisations have the goal to make the expression that needs to be translated simpler. In most cases this has a direct correspondence to smaller expressions. Shorter expressions will lead to a smaller translation, which leads to a smaller, but equivalent SAT formula. This potentially results in exponential speedups. In this section we give an overview of the implemented techniques.

4.1 Stratifying Definitions

Let-bindings are potentially very large, containing definitions for a lot of different symbols. Translating mutually recursive definitions leads to extra intermediate symbols in the translation process. Smaller, but deeper nested bindings explicitate that there is no recursion between symbols and result in better translations. We can use a topological ordering of the bindings to transform the bindings. Tarjan’s algorithm is used to find this ordering. This has already been done in other systems such as IDP3[7]. As a side effect of this topological ordering, definitions which are unused can be thrown away, because the formula after the “in” provides the starting points for the stratification. If a definition is unconnected to the formula, it is not included in the topological ordering.

Example 7. let odd x := even (x-1) ; even x := if x = 0 
then true else odd (x-1) ; c := 4 ; e := even c ; d := 8 in e.
can be stratified into:

```haskell
let odd x := ... ; even x := ... in
  (let c := 4 in (let e := even c in e)).
```

### 4.2 Inlining

Let-bindings contain definitions for certain symbols. These symbols occur in the inner expression of the let-binding. Sometimes it is beneficial to replace the defined symbol with its definition. It allows for other optimisations and prevents the need to always define the symbol. The process of replacing a symbol with its definition is called inlining. Inlining is done in a lot of major compilers. The GHC compiler for Haskell excels in this and we copied some of their techniques into FMS. One simple observation is that if a binding only has one single usage, it is always better to optimise the binding for this usage, as we can remove the original binding because it becomes unused.

**Example 8.** In the expression `let y := 2*x in y+5`, the variable `y` can easily be inlined, so the new expression becomes: `2*x+5`.

**Example 9.** In the expression `let y := f x in y+y`, the variable `y` would not be inlined, as `f x` would occur twice in the resulting expression, which could duplicate work in further steps.

Another inlining rule is that bindings to constant integers or strings should always be inlined, as handling those is generally not any more complex than handling a variable, but allows for more specialised optimisations. Sometimes the end user knows that inlining a function would be beneficial but the compiler could not derive this. For this reason FML allows for compiler directives which force the compiler to inline (or not inline) certain functions.

### 4.3 Boolean simplifications

When handling complex nested boolean formulas, applying some boolean rewrite rules can simplify them greatly. For this reason, pushing of negations is implemented just like in IDP3. This technique uses the standard rewriting rules for propositional and first order logic.

**Example 10.** The boolean expression `not (or (not p) (not q))` is simplified to the expression `and p q`

### 4.4 Constant folding and beta reductions

Constant folding is a common optimisation technique for compilers. Whenever the arguments of built-in functions like addition or multiplication are fully known, we can replace the expression with its evaluation. This can be extended to more
complex expressions: if the “if”-part of an if-then-else expression is trivially true, the if-then-else can be replaced by just the then-part.

When the arguments of an anonymous function are known, we can specialise the function body with the given arguments. This corresponds to the concept of beta reduction in the lambda calculus. Using beta reduction prevents the overhead of translating an extra lambda and can pair up with other optimisations such as constant folding for more efficiency gains.

**Example 11.** In the expression $(\lambda x . x + 4) ((\lambda x . 5) a)$, the second part $(\lambda x . 5) a$ can be beta reduced to 5. The resulting expression $(\lambda x . x + 4) 5$ can be beta reduced to $4 + 5$ which can be reduced to 9 through constant folding.

### 4.5 Combining the optimisations

All of the above optimisations can rewrite part of the expression tree. The application of an optimisation possibly opens up possibilities for other optimisations or sometimes, even the same optimisation. To fully optimise an expression, all optimisations should be repeated until a fixpoint on the expression is reached.

### 4.6 Future Optimisations

All above optimisations are already present in the current system. There are also a few optimisation techniques which have not been implemented but could be interesting future expansions.

**Rewrite Rules** Boolean simplifications are applications of rewrite rules which make the expressions simpler. If the user writes new complex functions, it can be beneficial that the end-user is able to write such rewrite rules for his own functions as meta-information for his definitions. This technique would be able to generalise the boolean simplifications and make it applicable to more situations. Such rules are already available in some programming languages such as Haskell.

**Example 12.** A rewriting rule like $\text{not} \ (\text{not} \ x) \Rightarrow x$ could explain that double negations can be ignored.

**Ground with Bounds** There are a lot of optimisations for grounding researched in the context of the IDP3 system. While some are subsumed by new techniques which are explained in this section, a lot of them are also applicable for the FML system. Grounding with bounds[20,21] is such a technique that proved to be significant for the performance of IDP3. Grounding with bounds uses symbolic reasoning to limit the size of quantifications. It is our hypothesis that these techniques generalize naturally to the higher order case of FML. This would allow quantifications over implicit domains so the forall quantifier could have type $(a \rightarrow \text{Bool}) \rightarrow \text{Bool}$ instead of type $\text{Set} \ a \rightarrow (a \rightarrow \text{Bool}) \rightarrow \text{Bool}$.
Example 13. Ground with bounds could rewrite an unbounded quantification like $\forall x \rightarrow (5 < x \& x > 10) \Rightarrow p(x)$ to a bounded expression $\forall \{6..9\} p(x)$ which can be handled by the algorithms which are already in place.

5 Dependencies and availability

The system is fully written in Kotlin, with a Gradle build system, in conjunction with a set of libraries. The most important ones are ANTLR4 for parsing, logback and slf4j for logging, JUnit for testing, and klaxon for JSON communication.

The software and its source can be found online at https://dtai.cs.kuleuven.be/krr/fms. There is support for testing the software online on the website itself or you can download it yourself. The only external dependency is Clingo, which can be downloaded from https://potassco.org/clingo/.

At the moment there is no IDE support for FML, but the development of an implementation for the Language Server Protocol[11] is in the early stages of development. This is a generic framework which editors can support to automate the integration with a new language.

6 Conclusion

This paper introduces FMS and its general internal workflow. As far as the authors are aware this is the first attempt for using a higher-order functional language as a modelling language. We introduced the Core language and its syntactical extensions into the Full language. We touched upon the different steps in the solving process and on the optimisation techniques which are available in the system. We also highlighted points where further work could significantly improve the system. A thorough comparison with other systems such as SMT or ASP is also an ambition for the close future. FMS is not a finished product yet, but it introduces some interesting new concepts.

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