PAKCS 1.12.0

The Portland Aachen Kiel Curry System

User Manual

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Contents

Preface 5

1 Overview of PAKCS 6
   1.1 General Use .................................................. 6
   1.2 Restrictions .................................................. 6
   1.3 Modules in PAKCS .............................................. 7

2 PAKCS: An Interactive Curry Development System 8
   2.1 Invoking PAKCS ............................................... 8
   2.2 Commands of PAKCS ........................................... 8
   2.3 Options of PAKCS ............................................ 11
   2.4 Using PAKCS in Batch Mode ................................. 14
   2.5 Command Line Editing ....................................... 15
   2.6 Customization ................................................ 15
   2.7 Emacs Interface ............................................. 15

3 Extensions 16
   3.1 Recursive Variable Bindings ............................... 16
   3.2 Functional Patterns ......................................... 16
   3.3 Order of Pattern Matching ................................. 18
   3.4 Datatypes with Field Labels .............................. 18
      3.4.1 Declaration of Constructors with Labeled Fields .. 18
      3.4.2 Field Selection ....................................... 19
      3.4.3 Construction Using Field Labels .................... 20
      3.4.4 Updates Using Field Labels .......................... 20
      3.4.5 Pattern Matching Using Field Labels ............... 21
      3.4.6 Field Labels and Modules ........................... 21

4 Recognized Syntax of Curry 22
   4.1 Notational Conventions ................................... 22
   4.2 Lexicon ..................................................... 22
      4.2.1 Case Mode ........................................... 22
      4.2.2 Identifiers and Keywords ............................ 22
      4.2.3 Comments ............................................ 23
      4.2.4 Numeric and Character Literals .................... 23
   4.3 Layout ....................................................... 24
   4.4 Context Free Grammar ..................................... 24

5 CurryDoc: A Documentation Generator for Curry Programs 28

6 CurryBrowser: A Tool for Analyzing and Browsing Curry Programs 31

7 CurryTest: A Tool for Testing Curry Programs 33
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 ERD2Curry: A Tool to Generate Programs from ER Specifications</td>
<td>35</td>
</tr>
<tr>
<td>9 Spicey: An ER-based Web Framework</td>
<td>36</td>
</tr>
<tr>
<td>10 UI: Declarative Programming of User Interfaces</td>
<td>37</td>
</tr>
<tr>
<td>11 Preprocessing FlatCurry Files</td>
<td>38</td>
</tr>
<tr>
<td>12 Technical Problems</td>
<td>40</td>
</tr>
<tr>
<td>Bibliography</td>
<td>41</td>
</tr>
</tbody>
</table>

A Libraries of the PAKCS Distribution

- A.1 Constraints, Ports, Meta-Programming
  - A.1.1 Arithmetic Constraints
  - A.1.2 Finite Domain Constraints
  - A.1.3 Ports: Distributed Programming in Curry
  - A.1.4 AbstractCurry and FlatCurry: Meta-Programming in Curry

- A.2 General Libraries
  - A.2.1 Library AllSolutions
  - A.2.2 Library Assertion
  - A.2.3 Library Char
  - A.2.4 Library CHR
  - A.2.5 Library CHRcompiled
  - A.2.6 Library CLPFD
  - A.2.7 Library CLPR
  - A.2.8 Library CLPB
  - A.2.9 Library Combinatorial
  - A.2.10 Library Constraint
  - A.2.11 Library CPNS
  - A.2.12 Library CSV
  - A.2.13 Library Database
  - A.2.14 Library Debug
  - A.2.15 Library Directory
  - A.2.16 Library Distribution
  - A.2.17 Library Dynamic
  - A.2.18 Library Either
  - A.2.19 Library FileGoodies
  - A.2.20 Library FilePath
  - A.2.21 Library Float
  - A.2.22 Library Function
  - A.2.23 Library FunctionInversion
  - A.2.24 Library GetOpt
  - A.2.25 Library Global
  - A.2.26 Library GlobalVariable
<table>
<thead>
<tr>
<th>Library Name</th>
<th>Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.2.27 Library GUI</td>
<td>92</td>
</tr>
<tr>
<td>A.2.28 Library Integer</td>
<td>104</td>
</tr>
<tr>
<td>A.2.29 Library IO</td>
<td>106</td>
</tr>
<tr>
<td>A.2.30 Library IOExts</td>
<td>108</td>
</tr>
<tr>
<td>A.2.31 Library JavaScript</td>
<td>110</td>
</tr>
<tr>
<td>A.2.32 Library KeyDatabase</td>
<td>113</td>
</tr>
<tr>
<td>A.2.33 Library KeyDatabaseSQLite</td>
<td>114</td>
</tr>
<tr>
<td>A.2.34 Library KeyDB</td>
<td>119</td>
</tr>
<tr>
<td>A.2.35 Library List</td>
<td>120</td>
</tr>
<tr>
<td>A.2.36 Library Maybe</td>
<td>124</td>
</tr>
<tr>
<td>A.2.37 Library NamedSocket</td>
<td>125</td>
</tr>
<tr>
<td>A.2.38 Library Parser</td>
<td>126</td>
</tr>
<tr>
<td>A.2.39 Library Ports</td>
<td>127</td>
</tr>
<tr>
<td>A.2.40 Library Pretty</td>
<td>130</td>
</tr>
<tr>
<td>A.2.41 Library Profile</td>
<td>139</td>
</tr>
<tr>
<td>A.2.42 Library Prolog</td>
<td>141</td>
</tr>
<tr>
<td>A.2.43 Library PropertyFile</td>
<td>143</td>
</tr>
<tr>
<td>A.2.44 Library Read</td>
<td>143</td>
</tr>
<tr>
<td>A.2.45 Library ReadNumeric</td>
<td>143</td>
</tr>
<tr>
<td>A.2.46 Library ReadShowTerm</td>
<td>144</td>
</tr>
<tr>
<td>A.2.47 Library SetFunctions</td>
<td>146</td>
</tr>
<tr>
<td>A.2.48 Library Socket</td>
<td>149</td>
</tr>
<tr>
<td>A.2.49 Library System</td>
<td>150</td>
</tr>
<tr>
<td>A.2.50 Library Time</td>
<td>151</td>
</tr>
<tr>
<td>A.2.51 Library Unsafe</td>
<td>154</td>
</tr>
<tr>
<td>A.3.1 Library Array</td>
<td>156</td>
</tr>
<tr>
<td>A.3.2 Library Dequeue</td>
<td>157</td>
</tr>
<tr>
<td>A.3.3 Library FiniteMap</td>
<td>158</td>
</tr>
<tr>
<td>A.3.4 Library GraphInductive</td>
<td>162</td>
</tr>
<tr>
<td>A.3.5 Library Random</td>
<td>168</td>
</tr>
<tr>
<td>A.3.6 Library RedBlackTree</td>
<td>168</td>
</tr>
<tr>
<td>A.3.7 Library SetRBT</td>
<td>169</td>
</tr>
<tr>
<td>A.3.8 Library Sort</td>
<td>170</td>
</tr>
<tr>
<td>A.3.9 Library TableRBT</td>
<td>171</td>
</tr>
<tr>
<td>A.3.10 Library Traversal</td>
<td>172</td>
</tr>
<tr>
<td>A.4.1 Library CategorizedHtmlList</td>
<td>174</td>
</tr>
<tr>
<td>A.4.2 Library HTML</td>
<td>175</td>
</tr>
<tr>
<td>A.4.3 Library HtmlCgi</td>
<td>187</td>
</tr>
<tr>
<td>A.4.4 Library HtmlParser</td>
<td>189</td>
</tr>
<tr>
<td>A.4.5 Library Mail</td>
<td>189</td>
</tr>
<tr>
<td>A.4.6 Library Markdown</td>
<td>190</td>
</tr>
<tr>
<td>A.4.7 Library URL</td>
<td>193</td>
</tr>
</tbody>
</table>
Preface

This document describes PAKCS (formerly called “PACS”), an implementation of the multi-paradigm language Curry, jointly developed at the University of Kiel, the Technical University of Aachen and Portland State University. Curry is a universal programming language aiming at the amalgamation of the most important declarative programming paradigms, namely functional programming and logic programming. Curry combines in a seamless way features from functional programming (nested expressions, lazy evaluation, higher-order functions), logic programming (logical variables, partial data structures, built-in search), and concurrent programming (concurrent evaluation of constraints with synchronization on logical variables). Moreover, the PAKCS implementation of Curry also supports constraint programming over various constraint domains, the high-level implementation of distributed applications, graphical user interfaces, and web services (as described in more detail in [12, 13, 14]). Since PAKCS compiles Curry programs into Prolog programs, the availability of some of these features might depend on the underlying Prolog system.

We assume familiarity with the ideas and features of Curry as described in the Curry language definition [20]. Therefore, this document only explains the use of the different components of PAKCS and the differences and restrictions of PAKCS (see Section 1.2) compared with the language Curry (Version 0.8.3).

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1 Overview of PAKCS

1.1 General Use

This version of PAKCS has been tested on Sun Solaris, Linux, and Mac OS X systems. In principle, it should also be executable on other platforms on which a Prolog system like SICStus-Prolog or SWI-Prolog exists (see the file INSTALL.html in the PAKCS directory for a description of the necessary software to install PAKCS).

All executable files required to use the different components of PAKCS are stored in the directory pakcshome/bin (where pakcshome is the installation directory of the complete PAKCS installation). You should add this directory to your path (e.g., by the bash command “export PATH=pakcshome/bin:$PATH”).

The source code of the Curry program must be stored in a file with the suffix “.curry”, e.g., prog.curry. Literate programs must be stored in files with the extension “.lcurry”.

Since the translation of Curry programs with PAKCS creates some auxiliary files (see Section D for details), you need write permission in the directory where you have stored your Curry programs. The auxiliary files for all Curry programs in the current directory can be deleted by the command cleancurry

(this is a shell script stored in the bin directory of the PAKCS installation, see above). The command

cleancurry -r

also deletes the auxiliary files in all subdirectories.

1.2 Restrictions

There are a few minor restrictions on Curry programs when they are processed with PAKCS:

- Singleton pattern variables, i.e., variables that occur only once in a rule, should be denoted as an anonymous variable “_”, otherwise the parser will print a warning since this is a typical source of programming errors.

- PAKCS translates all local declarations into global functions with additional arguments (“lambda lifting”, see Appendix D of the Curry language report). Thus, in the compiled target code, the definition of functions with local declarations look different from their original definition (in order to see the result of this transformation, you can use the CurryBrowser, see Section 6).

- Tabulator stops instead of blank spaces in source files are interpreted as stops at columns 9, 17, 25, 33, and so on. In general, tabulator stops should be avoided in source programs.

- Since PAKCS compiles Curry programs into Prolog programs, non-deterministic computations are treated as in Prolog by a backtracking strategy, which is known to be incomplete. Thus, the order of rules could influence the ability to find solutions for a given goal.

- Threads created by a concurrent conjunction are not executed in a fair manner (usually, threads corresponding to leftmost constraints are executed with higher priority).
Encapsulated search: In order to allow the integration of non-deterministic computations in programs performing I/O at the top-level, PAKCS supports the search operators \texttt{findall} and \texttt{findfirst}. These and some other operators are available in the library \texttt{Findall} (i.e., they are not part of the standard prelude). In contrast to the general definition of encapsulated search [19], the current implementation suspends the evaluation of \texttt{findall} and \texttt{findfirst} until the argument does not contain unbound global variables. Moreover, the evaluation of \texttt{findall} is strict, i.e., it computes all solutions before returning the complete list of solutions.

Since it is known that the result of these search operators might depend on the evaluation strategy due to the combination of sharing and lazy evaluation (see [9] for a detailed discussion), it is recommended to use \textit{set functions} [7] as a strategy-independent encapsulation of non-deterministic computations. Set functions compute the set of all results of a defined function but do not encapsulate non-determinism occurring in the actual arguments. See the library \texttt{SetFunctions} (Section A.2.47) for more details.

There is currently no general connection to external constraint solvers. However, the PAKCS compiler provides constraint solvers for arithmetic and finite domain constraints (see Appendix A).

1.3 Modules in PAKCS

PAKCS searches for imported modules in various directories. By default, imported modules are searched in the directory of the main program and the system module directories “\texttt{pakcshome/lib}” and “\texttt{pakcshome/lib/meta}”. This search path can be extended by setting the environment variable \texttt{CURRYPATH} (which can be also set in a PAKCS session by the option “:\texttt{set path}”, see below) to a list of directory names separated by colons (“;”). In addition, a local standard search path can be defined in the “.pakcsrc” file (see Section 2.6). Thus, modules to be loaded are searched in the following directories (in this order, i.e., the first occurrence of a module file in this search path is imported):

1. Current working directory (“.”) or directory prefix of the main module (e.g., directory “\texttt{/home/joe/curryprogs}” if one loads the Curry program “\texttt{/home/joe/curryprogs/main}”).

2. The directories enumerated in the environment variable \texttt{CURRYPATH}.

3. The directories enumerated in the “.pakcsrc” variable “libraries”.

4. The directories “\texttt{pakcshome/lib}” and “\texttt{pakcshome/lib/meta}”.

The same strategy also applies to modules with a hierarchical module name with the only difference that the hierarchy prefix of a module name corresponds to a directory prefix of the module. For instance, if the main module is stored in directory \texttt{MAINDIR} and imports the module \texttt{Test.Func}, then the module stored in \texttt{MAINDIR/Test/Func.curry} is imported (without setting any additional import path) according to the module search strategy described above.

Note that the standard prelude (\texttt{pakcshome/lib/Prelude.curry}) will be always implicitly imported to all modules if a module does not contain an explicit import declaration for the module Prelude.
2 PAKCS: An Interactive Curry Development System

PAKCS is an interactive system to develop applications written in Curry. It is implemented in Prolog and compiles Curry programs into Prolog programs. It contains various tools, a source-level debugger, solvers for arithmetic constraints over real numbers and finite domain constraints, etc. The compilation process and the execution of compiled programs is fairly efficient if a good Prolog implementation like SICStus-Prolog is used.

2.1 Invoking PAKCS

To start PAKCS, execute the command “pakcs” (this is a shell script stored in pakcs-home/bin where pakcs-home is the installation directory of PAKCS). When the system is ready (i.e., when the prompt “Prelude>” occurs), the prelude (pakcs-home/lib/Prelude.curry) is already loaded, i.e., all definitions in the prelude are accessible. Now you can type various commands (see next section) or an expression to be evaluated.

One can also invoke PAKCS with parameters. These parameters are usual a sequence of commands (see next section) that are executed before the user interaction starts. For instance, the invocation

pakcs :load Mod :add List

starts PAKCS, loads the main module Mod, and adds the additional module List. The invocation

pakcs :load Mod :eval config

starts PAKCS, loads the main module Mod, and evaluates the operation config before the user interaction starts. As a final example, the invocation

pakcs :load Mod :save :quit

starts PAKCS, loads the main module Mod, creates an executable, and terminates PAKCS. This invocation could be useful in “make” files for systems implemented in Curry.

There are also some specific options that can be used when invoking PAKCS:

-q or --quiet: With this option, PAKCS works silently, i.e., the initial banner and the input prompt are not shown. The output of other information is determined by the options “verbose” and “vn” (see Section 2.3).

--nolineedit: Do not use input line editing (see Section 2.5).

-Dname=val: Overwrite values defined in the configuration file “.pakcsrc” (see Section 2.6), where name is a property defined in the configuration file and val its new value.

2.2 Commands of PAKCS

The most important commands of PAKCS are (it is sufficient to type a unique prefix of a command if it is unique, e.g., one can type “:r” instead of “:reload”):

:help Show a list of all available commands.
(:load prog) Compile and load the program stored in prog.curry together with all its imported modules. If this file does not exist, the system looks for a FlatCurry file prog.fcy and compiles from this intermediate representation. If the file prog.fcy does not exist, too, the system looks for a file prog_flat.xml containing a FlatCurry program in XML representation (compare command ":.xml"), translates this into a FlatCurry file prog.fcy and compiles from this intermediate representation.

(:reload) Recompile all currently loaded modules.

(:add m₁...mn) Add modules m₁,...,mn to the set of currently loaded modules so that their exported entities are available in the top-level environment.

:expr] Evaluate the expression expr to normal form and show the computed results. Since PAKCS compiles Curry programs into Prolog programs, non-deterministic computations are implemented by backtracking. Therefore, computed results are shown one after the other. In the interactive mode (which can be set in the configuration file ".pakcsr" or by setting the option interactive, see below), you will be asked after each computed result whether you want to see the next alternative result or all alternative results. The default answer value for this question can be defined in the configuration file ".pakcsr" file (see Section 2.6).

Free variables in initial expressions must be declared as in Curry programs (if the free variable mode is not turned on, see option "+free" below). Thus, in order to see the results of their bindings, they must be introduced by a "where...free" declaration. For instance, one can write

not b where b free

in order to obtain the following bindings and results:

{b = True} False
{b = False} True

Without these declarations, an error is reported in order to avoid the unintended introduction of free variables in initial expressions by typos.

(:eval expr] Same as expr. This command might be useful when putting commands as arguments when invoking pакcs.

(:define x=expr] Define the identifier x as an abbreviation for the expression expr which can be used in subsequent expressions. The identifier x is visible until the next load or reload command.

(:quit] Exit the system.

There are also a number of further commands that are often useful:

(:type expr] Show the type of the expression expr.

(:browse] Start the CurryBrowser to analyze the currently loaded module together with all its imported modules (see Section 6 for more details).
:edit Load the source code of the current main module into a text editor. If the variable editcommand is set in the configuration file ".pakcsr" (see Section 2.6), its value is used as an editor command, otherwise the environment variable "EDITOR" or a default editor (e.g., "vi") is used.

:edit m Load the source text of module m (which must be accessible via the current load path if no path specification is given) into a text editor which is defined as in the command ":edit".

:interface Show the interface of the currently loaded module, i.e., show the names of all imported modules, the fixity declarations of all exported operators, the exported datatypes declarations and the types of all exported functions.

:interface prog Similar to ":interface" but shows the interface of the module "prog.curry". If this module does not exist, this command looks in the system library directory of PAKCS for a module with this name, e.g., the command ":interface FlatCurry" shows the interface of the system module FlatCurry for meta-programming (see Appendix A.1.4).

:usedimports Show all calls to imported functions in the currently loaded module. This might be useful to see which import declarations are really necessary.

:modules Show the list of all currently loaded modules.

:programs Show the list of all Curry programs that are available in the load path.

:set option Set or turn on/off a specific option of the PAKCS environment (see 2.3 for a description of all options). Options are turned on by the prefix "+" and off by the prefix "-". Options that can only be set (e.g., printdepth) must not contain a prefix.

:set Show a help text on the possible options together with the current values of all options.

:show Show the source text of the currently loaded Curry program. If the variable showcommand is set in the configuration file ".pakcsr" (see Section 2.6), its value is used as a command to show the source text, otherwise the environment variable PAGER or the standard command "cat" is used. If the source text is not available (since the program has been directly compiled from a FlatCurry or XML file), the loaded program is decompiled and the decompiled Curry program text is shown.

:show m Show the source text of module m which must be accessible via the current load path.

:source f Show the source code of function f (which must be visible in the currently loaded module) in a separate window.

:source m.f Show the source code of function f defined in module m in a separate window.

:cd dir Change the current working directory to dir.

:dir Show the names of all Curry programs in the current working directory.

:!cmd Shell escape: execute cmd in a Unix shell.
:save
Save the currently loaded program as an executable evaluating the main expression “main”. The executable is stored in the file Mod if Mod is the name of the currently loaded main module.

:save expr
Similar as “:save” but the expression expr (typically: a call to the main function) will be evaluated by the executable.

:fork expr
The expression expr, which must be of type “IO ()”, is evaluated in an independent process which runs in parallel to the current PAKCS process. All output and error messages from this new process are suppressed. This command is useful to test distributed Curry programs (see Appendix A.1.3) where one can start a new server process by this command. The new process will be terminated when the evaluation of the expression expr is finished.

:coosy
Start the Curry Object Observation System COOSy, a tool to observe the execution of Curry programs. This command starts a graphical user interface to show the observation results and adds to the load path the directory containing the modules that must be imported in order to annotate a program with observation points. Details about the use of COOSy can be found in the COOSy interface (under the “Info” button), and details about the general idea of observation debugging and the implementation of COOSy can be found in [8].

:xml
Translate the currently loaded program module into an XML representation according to the format described in http://www.informatik.uni-kiel.de/~curry/flat/. Actually, this yields an implementation-independent representation of the corresponding FlatCurry program (see Appendix A.1.4 for a description of FlatCurry). If prog is the name of the currently loaded program, the XML representation will be written into the file “prog_flat.xml”.

:peval
Translate the currently loaded program module into an equivalent program where some subexpressions are partially evaluated so that these subexpressions are (hopefully) more efficiently executed. An expression e to be partially evaluated must be marked in the source program by (PEVAL e) (where PEVAL is defined as the identity function in the prelude so that it has no semantical meaning).

The partial evaluator translates a source program prog.curry into the partially evaluated program in intermediate representation stored in prog_pe.fcy. The latter program is implicitly loaded by the peval command so that the partially evaluated program is directly available. The corresponding source program can be shown by the show command (see above).

The current partial evaluator is an experimental prototype (so it might not work on all programs) based on the ideas described in [1, 2, 3, 4].

2.3 Options of PAKCS

The following options (which can be set by the command “:set”) are currently supported:

+/-debug
Debug mode. In the debug mode, one can trace the evaluation of an expression, setting spy points (break points) etc. (see the commands for the debug mode described below).

+/-free
Free variable mode. If the free variable mode is off (default), then free variables occurring in initial expressions entered in the PAKCS environment must always be declared by
“where...free”. This avoids the introduction of free variables in initial expressions by typos (which might lead to the exploration of infinite search spaces). If the free variable mode is on, each undefined symbol occurring in an initial expression is considered as a free variable. In this case, the syntax of accepted initial expressions is more restricted. In particular, lambda abstractions, \texttt{let}s and list comprehensions are not allowed if the free variable mode is on.

\textbf{+/-printfail} Print failures. If this option is set, failures occurring during evaluation (i.e., non-reducible demanded subexpressions) are printed. This is useful to see failed reductions due to partially defined functions or failed unifications. Inside encapsulated search (e.g., inside evaluations of \texttt{findall} and \texttt{findfirst}), failures are not printed (since they are a typical programming technique there). Note that this option causes some overhead in execution time and memory so that it could not be used in larger applications.

\textbf{+/-allfails} If this option is set, all failures (i.e., also failures on backtracking and failures of enclosing functions that fail due to the failure of an argument evaluation) are printed if the option \texttt{printfail} is set. Otherwise, only the first failure (i.e., the first non-reducible subexpression) is printed.

\textbf{+/-consfail} Print constructor failures. If this option is set, failures due to application of functions with non-exhaustive pattern matching or failures during unification (application of “\texttt{=:}”) are shown. Inside encapsulated search (e.g., inside evaluations of \texttt{findall} and \texttt{findfirst}), failures are not printed (since they are a typical programming technique there). In contrast to the option \texttt{printfail}, this option creates only a small overhead in execution time and memory use.

\textbf{+consfail all} Similarly to “+consfail”, but the complete trace of all active (and just failed) function calls from the main function to the failed function are shown.

\textbf{+consfail file:f} Similarly to “+consfail all”, but the complete fail trace is stored in the file \texttt{f}. This option is useful in non-active program executions like web scripts.

\textbf{+consfail int} Similarly to “+consfail all”, but after each failure occurrence, an interactive mode for exploring the fail trace is started (see help information in this interactive mode). When the interactive mode is finished, the program execution proceeds with a failure.

\textbf{+/-compact} Reduce the size of target programs by using the parser option “--compact” (see Section \ref{sec:deptree} for details about this option).

\textbf{+/-interactive} Turn on/off the interactive mode. In the interactive mode, the next non-deterministic value is computed only when the user requests it. Thus, one has also the possibility to terminate the enumeration of all values after having seen some values. The default value for this option can be set in the configuration file “.pakcsrc” (initially, the interactive mode is turned off).

\textbf{+/-first} Turn on/off the first-only mode. In the first-only mode, only the first value of the main expression is printed (instead of all values).
Profile mode. If the profile mode is on, then information about the number of calls, failures, exits etc. are collected for each function during the debug mode (see above) and shown after the complete execution (additionaly, the result is stored in the file prog.profile where prog is the current main program). The profile mode has no effect outside the debug mode.

Suspend mode (initially, it is off). If the suspend mode is on, all suspended expressions (if there are any) are shown (in their internal representation) at the end of a computation.

Time mode. If the time mode is on, the cpu time and the elapsed time of the computation is always printed together with the result of an evaluation.

Verbose mode (initially, it is off). If the verbose mode is on, the initial expression of a computation is printed before it is evaluated. If the verbose mode is on and the verbosity level (see below) is non-zero, the type of the initial expression is also printed and the output of the evaluation is more detailed.

Parser warnings. If the parser warnings are turned on (default), the parser will print warnings about variables that occur only once in a program rule (see Section 1.2) or locally declared names that shadow the definition of globally declared names. If the parser warnings are switched off, these warnings are not printed during the reading of a Curry program.

Set the additional search path for loading modules to path. Note that this search path is only used for loading modules inside this invocation of PAKCS, i.e., the environment variable “CURRYPATH” (see also Section 1.3) is set to path in this invocation of PAKCS.

The path is a list of directories separated by “;”. The prefix “~” is replaced by the home directory as in the following example:

: set path aux:~/tests

Relative directory names are replaced by absolute ones so that the path is independent of later changes of the current working directory.

Set the depth for printing terms to the value n (initially: 10). In this case subterms with a depth greater than n are abbreviated by dots when they are printed as a result of a computation or during debugging. A value of 0 means infinite depth so that the complete terms are printed.

Set the verbosity level to n. The following values are allowed for n:

- n = 0: Do not show any messages (except for errors).
- n = 1: Show only messages of the front-end, like loading of modules.
- n = 2: Show also messages of the back end, like loading intermediate files or generating Prolog target files.
- n = 3: Show also messages related to loading Prolog files and libraries into the run-time systems and other intermediate messages and results.
Turn on the safe execution mode. In the safe execution mode, the initial goal is not allowed to be of type `IO` and the program should not import the module `Unsafe`. Furthermore, the allowed commands are `eval`, `load`, `quit`, and `reload`. This mode is useful to use PAKCS in uncontrolled environments, like a computation service in a web page, where PAKCS could be invoked by

```
pakcs :set safe
```

Define additional options passed to the PAKCS front end, i.e., the parser program `pakcshome/bin/cymake`. For instance, setting the option

```
:set parser -F --pgmF=transcurry
```

has the effect that each Curry module to be compiled is transformed by the preprocessor command `transcurry` into a new Curry program which is actually compiled.

Define run-time arguments for the evaluation of the main expression. For instance, setting the option

```
:set args first second
```

has the effect that the I/O operation `getArgs` (see library `System` (Section A.2.49) returns the value `"first","second"`).

PAKCS can also execute programs in the **debug mode**. The debug mode is switched on by setting the `debug` option with the command `:set +debug`. In order to switch back to normal evaluation of the program, one has to execute the command `:set -debug`.

In the debug mode, PAKCS offers the following additional options:

```
+-single
```

Turn on/off single mode for debugging. If the single mode is on, the evaluation of an expression is stopped after each step and the user is asked how to proceed (see the options there).

```
+-trace
```

Turn on/off trace mode for debugging. If the trace mode is on, all intermediate expressions occurring during the evaluation of an expressions are shown.

```
spy f
```

Set a spy point (break point) on the function `f`. In the single mode, you can “leap” from spy point to spy point (see the options shown in the single mode).

```
+-spy
```

Turn on/off spy mode for debugging. If the spy mode is on, the single mode is automatically activated when a spy point is reached.

### 2.4 Using PAKCS in Batch Mode

Although PAKCS is primarily designed as an interactive system, it can also be used to process data in batch mode. For example, consider a Curry program, say `myprocessor`, that reads argument strings from the command line and processes them. Suppose the entry point is a function called `just_doit` that takes no arguments. Such a processor can be invoked from the shell as follows:
The “:quit” directive is necessary to avoid PAKCS going into interactive mode after the execution of the expression being evaluated. The actual run-time arguments (string1, string2) are defined by setting the option args (see above).

Here is an example to use PAKCS in this way:

```plaintext
> pakcs :set args Hello World :add System :eval "getArgs >>= putStrLn . unwords" :quit
Hello World
```

2.5 Command Line Editing

In order to have support for line editing or history functionality in the command line of PAKCS (as often supported by the readline library), you should have the Unix command rlwrap installed on your local machine. If rlwrap is installed, it is used by PAKCS if called on a terminal. If it should not be used (e.g., because it is executed in an editor with readline functionality), one can call PAKCS with the parameter “--noreadline”.

2.6 Customization

In order to customize the behavior of PAKCS to your own preferences, there is a configuration file which is read by PAKCS when it is invoked. When you start PAKCS for the first time, a standard version of this configuration file is copied with the name “.pakcsr” into your home directory. The file contains definitions of various settings, e.g., about showing warnings, progress messages etc. After you have started PAKCS for the first time, look into this file and adapt it to your own preferences.

2.7 Emacs Interface

Emacs is a powerful programmable editor suitable for program development. It is freely available for many platforms (see http://www.emacs.org). The distribution of PAKCS contains also a special Curry mode that supports the development of Curry programs in the Emacs environment. This mode includes support for syntax highlighting, finding declarations in the current buffer, and loading Curry programs into PAKCS in an Emacs shell.

The Curry mode has been adapted from a similar mode for Haskell programs. Its installation is described in the file README in directory “pakcshome/tools/emacs” which also contains the sources of the Curry mode and a short description about the use of this mode.
3 Extensions

PAKCS supports some extensions in Curry programs that are not (yet) part of the definition of Curry. These extensions are described below.

3.1 Recursive Variable Bindings

Local variable declarations (introduced by let or where) can be (mutually) recursive in PAKCS. For instance, the declaration

\[
\text{ones5} = \text{let ones} = 1 : \text{ones} \\
in \text{take 5 ones}
\]

introduces the local variable ones which is bound to a cyclic structure representing an infinite list of 1’s. Similarly, the definition

\[
\text{onetwo n} = \text{take n one2} \\
\text{where} \\
\text{one2} = 1 : \text{two1} \\
\text{two1} = 2 : \text{one2}
\]

introduces a local variables one2 that represents an infinite list of alternating 1’s and 2’s so that the expression (onetwo 6) evaluates to [1,2,1,2,1,2].

3.2 Functional Patterns

Functional patterns [6] are a useful extension to code operations in a more readable way. Furthermore, defining operations with functional patterns avoids problems caused by strict equality (“\(=:=\)”) and leads to programs that are potentially more efficient.

Consider the definition of an operation to compute the last element of a list xs based on the prelude operation \(++\) for list concatenation:

\[
\text{last xs | _++[y]} =:= \text{xs} = y \quad \text{where} \ y \ \text{free}
\]

Since the equality constraint \(=:=\) evaluates both sides to a constructor term, all elements of the list xs are fully evaluated in order to satisfy the constraint.

Functional patterns can help to improve this computational behavior. A functional pattern is a function call at a pattern position. With functional patterns, we can define the operation last as follows:

\[
\text{last (_++[y])} = \ y
\]

This definition is not only more compact but also avoids the complete evaluation of the list elements: since a functional pattern is considered as an abbreviation for the set of constructor terms obtained by all evaluations of the functional pattern to normal form (see [6] for an exact definition), the previous definition is conceptually equivalent to the set of rules

\[
\text{last [y]} = \ y \\
\text{last [_,y]} = \ y \\
\text{last [_,_,y]} = \ y \\
\ldots
\]
which shows that the evaluation of the list elements is not demanded by the functional pattern.

In general, a pattern of the form \((f \ t_1 \ldots t_n) (n > 0)\) is interpreted as a functional pattern if \(f\) is not a visible constructor but a defined function that is visible in the scope of the pattern.

It is also possible to combine functional patterns with as-patterns. Similarly to the meaning of as-patterns in standard constructor patterns, as-patterns in functional patterns are interpreted as a sequence of pattern matching where the variable of the as-pattern is matched before the given pattern is matched. This process can be described by introducing an auxiliary operation for this two-level pattern matching process. For instance, the definition

\[
f (_ \++ x@[(42,\_)] \++ _) = x
\]

is considered as syntactic sugar for the expanded definition

\[
f (_ \++ x \++ _) = f' x
\]

where

\[
f' [(42,\_)] = x
\]

However, as-patterns are usually implemented in a more efficient way without introducing auxiliary operations.

**Optimization of programs containing functional patterns.** Since functions patterns can evaluate to non-linear constructor terms, they are dynamically checked for multiple occurrences of variables which are, if present, replaced by equality constraints so that the constructor term is always linear (see [6] for details). Since these dynamic checks are costly and not necessary for functional patterns that are guaranteed to evaluate to linear terms, there is an optimizer for functional patterns that checks for occurrences of functional patterns that evaluate always to linear constructor terms and replace such occurrences with a more efficient implementation. This optimizer can be enabled by the following possibilities:

- Set the environment variable FCYPP to “--fpopt” before starting PAKCS, e.g., by the shell command

  \[
  \text{export FCYPP="--fpopt"}
  \]

  Then the functional pattern optimization is applied if programs are compiled and loaded in PAKCS.

- Put an option into the source code: If the source code of a program contains a line with a comment of the form (the comment must start at the beginning of the line)

  \[
  \{-# PAKCS\_OPTION\_FCYPP --fpopt #-}
  \]

  then the functional pattern optimization is applied if this program is compiled and loaded in PAKCS.

The optimizer also report errors in case of wrong uses of functional patterns (i.e., in case of a function \(f\) defined with functional patterns that recursively depend on \(f\)).
3.3 Order of Pattern Matching

Curry allows multiple occurrences of pattern variables in standard patterns. These are an abbreviation of equational constraints between pattern variables. Functional patterns might also contain multiple occurrences of pattern variables. For instance, the operation

\[ f \ (\_\_+\_[x]+\_\_+\_\_+\_\_\_\_) = x \]

returns all elements with at least two occurrences in a list.

If functional patterns as well as multiple occurrences of pattern variables occur in a pattern defining an operation, there are various orders to match an expression against such an operation. In the current implementation, the order is as follows:

1. Standard pattern matching: First, it is checked whether the constructor patterns match. Thus, functional patterns and multiple occurrences of pattern variables are ignored.

2. Functional pattern matching: In the next phase, functional patterns are matched but occurrences of standard pattern variables in the functional patterns are ignored.

3. Non-linear patterns: If standard and functional pattern matching is successful, the equational constraints which correspond to multiple occurrences pattern variables are solved.

4. Guards: Finally, the guards supplied by the programmer are checked.

The order of pattern matching should not influence the computed result. However, it might have some influence on the termination behavior of programs, i.e., a program might not terminate instead of finitely failing. In such cases, it could be necessary to consider the influence of the order of pattern matching. Note that other orders of pattern matching can be obtained using auxiliary operations.

3.4 Datatypes with Field Labels

A datatype declaration may optionally define data constructors with field labels. These field labels can be used to construct, select from, and update fields in a manner that is independent of the overall structure of the datatype.

3.4.1 Declaration of Constructors with Labeled Fields

A data constructor of arity \( n \) creates an object with \( n \) components. These components are normally accessed positionally as arguments to the constructor in expressions or patterns. For large datatypes it is useful to assign field labels to the components of a data object. This allows a specific field to be referenced independently of its location within the constructor. A constructor definition in a data declaration may assign labels to the fields of the constructor, using the record syntax \( c \ \{ \ldots \} \).

Constructors using field labels may be freely mixed with constructors without them. A constructor with associated field labels may still be used as an ordinary constructor. The various use of labels (see below) are simply a shorthand for operations using an underlying positional constructor. The arguments to the positional constructor occur in the same order as the labeled fields.

\[ ^1 \text{Field labels are quite similar to Haskell} \ [22] \text{ so that we adopt most of the description of Haskell here.} \]
For example, the definition using field labels

```haskell
data Person = Person { firstName, lastName :: String, age :: Int }
  | Agent   { firstName, lastName :: String, trueIdentity :: Person }
```

is translated to

```haskell
data Person = Person String String Int
  | Agent String String Person
```

A data declaration may use the same field label in multiple constructors as long as the typing of the field is the same in all cases after type synonym expansion. A label cannot be shared by more than one type in scope. Field names share the top-level name space with ordinary definition of functions and must not conflict with other top-level names in scope.

Consider the following example:

```haskell
data S = S1 { x :: Int } | S2 { x :: Int } -- OK
data T = T1 { y :: Int } | T2 { y :: Bool } -- BAD
```

Here S is legal but T is not, because y is given inconsistent typings in the latter.

### 3.4.2 Field Selection

Field labels are used as selector functions, i.e., each field label serves as a function that extracts the field from an object. Selectors are top-level bindings and so they may be shadowed by local variables but cannot conflict with other top-level bindings of the same name. This shadowing only affects selector functions; in record construction (Section 3.4.3) and update (Section 3.4.4), field labels cannot be confused with ordinary variables.

**Translation:** A field label $lab$ introduces a selector function defined as:

$$
lab \ (C \ p_{11} \ldots p_{1k_1}) = x
$$

$$
\ldots
$$

$$
lab \ (C \ p_{n1} \ldots p_{nk_n}) = x
$$

where $C_1 \ldots C_n$ are all the constructors of the datatype containing a field labeled with $lab$, $p_{ij}$ is $x$ when $lab$ labels the $j$th component of $C_i$ or $\_\_$ otherwise.

For example the definition of $Person$ above introduces the selector functions

```haskell
firstName :: Person → String
firstName (Person x _ _) = x
firstName (Agent x _ _) = x
```

```haskell
lastName :: Person → String
lastName (Person _ x _) = x
```
lastName (Agent _ x _) = x

age :: Person → Int
age (Person _ _ x) = x

trueIdentity :: Person → Person
trueIdentity (Agent _ _ x) = x

### 3.4.3 Construction Using Field Labels

A constructor with labeled fields may be used to construct a value in which the components are specified by name rather than by position. In this case, the components are enclosed by braces. Construction using field labels is subject to the following constraints:

- Only field labels declared with the specified constructor may be mentioned.
- A field label may not be mentioned more than once.
- Fields not mentioned are initialized to different free variables.

The expression `C{}`, where `C` is a data constructor, is legal \textit{whether or not `C` was declared with record syntax}; it denotes \texttt{C Prelude.unknown, ... Prelude.unknown}, where `n` is the arity of `C`. Note that this will introduce the constructor `C` with \textit{n different} free variables as arguments.

#### Translation

The auxiliary function `pick_C^i bs d` is defined as follows:

- If the `i`th component of a constructor `C` has the field label `f` and `f = v` appears in the binding list `bs`, then `pick_C^i bs d` is `v`. Otherwise, `pick_C^i bs d` is the default value `d`.

For example, a \texttt{Person} can be constructed by

```
smith = Agent { lastName = "Smith", firstName = "Agent" }
```

which is equivalent to the following agent, whose true identity might be any person:

```
smith = Agent "Agent" "Smith" _
```

### 3.4.4 Updates Using Field Labels

Values belonging to a datatype with field labels may be non-destructively updated. This creates a new value in which the specified field values replace those in the existing value. Updates are restricted in the following ways:

- All labels must be taken from the same datatype.
- No label may be mentioned more than once.
• The computation fails when the value being updated does not contain all of the specified labels.

**Translation:** Using the prior definition of pick,

\[
e \{ bs \} = \text{fcase } e \text{ of } \\
C_1 \, v_1 \ldots v_{k_1} \rightarrow C_1 \, (\text{pick}^{C_1}_{k_1} \, bs \, v_1) \ldots (\text{pick}^{C_1}_{k_1} \, bs \, v_{k_1}) \\
\ldots \\
C_j \, v_1 \ldots v_{k_j} \rightarrow C_j \, (\text{pick}^{C_j}_{k_j} \, bs \, v_1) \ldots (\text{pick}^{C_j}_{k_j} \, bs \, v_{k_j})
\]

where \( \{C_1, \ldots, C_j\} \) is the set of constructors containing all labels in \( bs \), \( k_i \) is the arity of \( C_i \).

For example, after watching a few more movies, we might want to update our information about smith. We can do so by writing

```plaintext
smith \{ trueIdentity = complement neo \}
```

which is equivalent to

```plaintext
\text{fcase smith of } \\
\quad \text{Agent fn ln } _ \rightarrow \text{Agent fn ln (complement neo)}
```

### 3.4.5 Pattern Matching Using Field Labels

A constructor with labeled fields may be used to specify a pattern in which the components are identified by name rather than by position. Matching against a constructor using labeled fields is the same as matching ordinary constructor patterns except that the fields are matched in the order they are named in the field list. All listed fields must be declared by the constructor; fields may not be named more than once. Fields not named by the pattern are ignored (matched against \( _ \)).

**Translation:** Using the prior definition of pick,

\[
C \{ bs \} = (C \, (\text{pick}^{C}_{k} \, bs \, _) \ldots (\text{pick}^{C}_{k} \, bs \, _))
\]

where \( k \) is the arity of \( C \).

For example, we could define a Smith-tester by writing:

```plaintext
isSmith Agent \{ lastName = "Smith" \} = success
```

which is equivalent to

```plaintext
isSmith (Agent _ "Smith" _) = success
```

### 3.4.6 Field Labels and Modules

As described in the Curry report, there are two forms of exporting a data type \( T \): The simple name \( T \) exports only the types name without constructors, whereas \( T(\ldots) \) also exports all constructors. Analogously, the form \( T \) does not export any field labels, whereas \( T(\ldots) \) exports all constructors and all field labels.
4 Acknowledged Syntax of Curry

The PAKCS Curry compiler accepts a slightly extended version of the grammar specified in the Curry Report [20]. Furthermore, the syntax recognized by PAKCS differs from that specified in the Curry Report regarding numeric or character literals. We therefore present the complete description of the syntax below, whereas syntactic extensions are highlighted.

4.1 Notational Conventions

The syntax is given in extended Backus-Naur-Form (eBNF), using the following notation:

\[
\begin{align*}
    NonTerm & ::= \alpha \quad \text{production} \\
    NonTerm & ::= \text{nonterminal symbol} \\
    Term & ::= \text{terminal symbol} \\
    [\alpha] & ::= \text{optional} \\
    \{\alpha\} & ::= \text{zero or more repetitions} \\
    (\alpha) & ::= \text{grouping} \\
    \alpha | \beta & ::= \text{alternative} \\
    \alpha \langle \beta \rangle & ::= \text{difference – elements generated by } \alpha \\
    \text{without those generated by } \beta \\
\end{align*}
\]

The Curry files are expected to be encoded in UTF8. However, source programs are biased towards ASCII for compatibility reasons.

4.2 Lexicon

4.2.1 Case Mode

Although the Curry Report specifies four different case modes (Prolog, Gödel, Haskell, free), the PAKCS only supports the free mode which puts no constraints on the case of identifiers.

4.2.2 Identifiers and Keywords

\[
\begin{align*}
    \text{Letter} & ::= \text{any ASCII letter} \\
    \text{Dashes} & ::= \text{-- \{-\}} \\
    \text{Ident} & ::= \text{Letter \{Letter \| Digit \| \_ \| \'} \} \\
    \text{Symbol} & ::= \text{~ \| ! \| @ \| \# \| \$ \| % \| \^ \| \& \| \* \| + \| - \| = \| < \| > \| ? \| . \| / \| I \| \_ \| :} \\
    \text{ModuleID} & ::= \text{\{Ident . \} Ident} \\
    \text{TypeConstrID} & ::= \text{Ident} \\
    \text{DataConstrID} & ::= \text{Ident} \\
    \text{TypeVarID} & ::= \text{Ident \| \_} \\
    \text{InfixOpID} & ::= \text{Symbol \{Symbol\}\{Dashes\}} \\
    \text{FunctionID} & ::= \text{Ident} \\
    \text{VariableID} & ::= \text{Ident} \\
    \text{LabelID} & ::= \text{Ident}
\end{align*}
\]
\textbf{QTypeConstrID} ::= [\text{ModuleID} .] \text{TypeConstrID} \\
\text{QDataConstrID} ::= [\text{ModuleID} .] \text{DataConstrID} \\
\text{QInfixOpID} ::= [\text{ModuleID} .] \text{InfixOpID} \\
\text{QFunctionID} ::= [\text{ModuleID} .] \text{FunctionID} \\
\text{QVariableID} ::= [\text{ModuleID} .] \text{VariableID} \\
\text{QLabelID} ::= [\text{ModuleID} .] \text{LabelID}

The following identifiers are recognized as keywords and cannot be used as an identifier:

\begin{verbatim}
case data do else external fcase foreign free if import in infix infixl infixr let module newtype of then type where
\end{verbatim}

Note that the symbols \textit{as}, \textit{hiding} and \textit{qualified} are not keywords. They have only a special meaning in module headers and can be used as ordinary identifiers.

The following symbols also have a special meaning and cannot be used as an infix operator identifier:

\begin{verbatim}
.. :: = | <- -> @ ~
\end{verbatim}

4.2.3 Comments

Comments begin either with \textit{\text{"--\text{}} and terminate at the end of the line or with \textit{\text{\{--\text{}}} and terminate with a matching \textit{\text{\text{}}}, i.e., the delimiters \textit{\text{\{--\text{}}} and \textit{\text{\text{}}} act as parentheses and can be nested.

4.2.4 Numeric and Character Literals

Contrasting to the Curry Report, PAKCS adopts Haskell’s notation of literals, for both numeric literals as well as \textit{Char} and \textit{String} literals. The precise syntax for both kinds is given below.

\begin{verbatim}
Int ::= Decimal \\
\quad | 0o Octal | 0O Octal \\
\quad | 0x Hexadecimal | 0X Hexadecimal

Float ::= Decimal . Decimal [Exponent] \\
\quad | Decimal Exponent

Exponent ::= (e | E) [+ | -] Decimal

Decimal ::= Digit [Decimal] \\
Binary ::= Binit [Binary] \\
Octal ::= Octit [Octal] \\
Hexadecimal ::= Hexit [Hexadecimal]

Digit ::= 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9

Binit ::= 0 | 1

Octit ::= 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7

Hexit ::= 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | A | B | C | D | E | F | a | b | c | d | e | f

Char ::= ’(Graphic \langle \text\_\rangle | Space | Escape \langle \text\_\rangle)’

String ::= ”(Graphic \langle \text\_\rangle | Space | Escape \langle Gap\rangle)”

Escape ::= \langle CharEsc | Ascii | Decimal | o Octal | x Hexadecimal\rangle
\end{verbatim}
4.3 Layout

Similarly to Haskell, a Curry programmer can use layout information to define the structure of blocks. For this purpose, we define the indentation of a symbol as the column number indicating the start of this symbol. The indentation of a line is the indentation of its first symbol.²

The layout (or “off-side”) rule applies to lists of syntactic entities after the keywords let, where, do, or of. In the subsequent context-free syntax, these lists are enclosed with curly brackets ({}), and the single entities are separated by semicolons (;). Instead of using the curly brackets and semicolons of the context-free syntax, a Curry programmer must specify these lists by indentation: the indentation of a list of syntactic entities after let, where, do, or of is the indentation of the next symbol following the let, where, do, of. Any item of this list start with the same indentation as the list. Lines with only whitespaces or an indentation greater than the indentation of the list continue the item in its previous line. Lines with an indentation less than the indentation of the list terminate the entire list. Moreover, a list started by let is terminated by the keyword in. Thus, the sentence

\[ f \ x = h \ x \ where \ \{ \ g \ y = y + 1 ; \ h \ z = (g \ z) * 2 \}\]

which is valid w.r.t. the context-free syntax, is written with the layout rules as

\[ f \ x = h \ x \]
\[ \where \ g \ y = y + 1 \]
\[ h \ z = (g \ z) * 2 \]

or also as

\[ f \ x = h \ x \ where \]
\[ g \ y = y + 1 \]
\[ h \ z = (g \ z) \]
\[ * 2 \]

To avoid an indentation of top-level declarations, the keyword module and the end-of-file token are assumed to start in column 0.

4.4 Context Free Grammar

\[
Module ::= \text{module } ModuleID [Exports] \ where \ Block \\
| \ Block
\]

²In order to determine the exact column number, we assume a fixed-width font with tab stops at each 8th column.
ModuleID ::= see lexicon
Exports ::= ( Export1, ..., Exportn ) (n ≥ 0)
Export ::= QFunctionName
| QTypeConstrID [( ConsLabelName1, ..., ConsLabelName_n )] (n ≥ 0)
| QTypeConstrID (...)
| module ModuleID
ConsLabelName ::= LabelID | DataConstr
Block ::= { [ImportDecl1; ...; ImportDeclk];
BlockDeclaration1; ...; BlockDeclarationn } (no fixity declarations here)(k, n ≥ 0)
ImportDecl ::= import [qualified] ModuleID [as ModuleID] [ImportRestr]
ImportRestr ::= ( Import1, ..., Importn ) (n ≥ 0)
| hiding ( Import1, ..., Importn ) (n ≥ 0)
Import ::= FunctionName
| TypeConstrID [( ConsLabelName1, ..., ConsLabelName_n )] (n ≥ 0)
| TypeConstrID (...)
BlockDeclaration ::= TypeSynonymDecl
| DataDeclaration
| FixityDeclaration
| FunctionDeclaration
TypeSynonymDecl ::= type SimpleType = TypeExpr
SimpleType ::= TypeConstrID TypeVarID1 ... TypeVarIDn (n ≥ 0)
TypeConstrID ::= see lexicon
DataDeclaration ::= data SimpleType (external data type)
| data SimpleType = ConstrDecl1 | ... | ConstrDecln (n > 0)
ConstrDecl ::= DataConstr SimpleTypeExpr1 ... SimpleTypeExprn (n ≥ 0)
| SimpleTypeExpr ConsOp TypeConsExpr (infix data constructor)
| DataConstr { FieldDeclaration1, ..., FieldDeclarationn } (n ≥ 0)
FieldDeclaration ::= LabelID1, ..., LabelIDn :: TypeExpr (n > 0)
LabelID ::= see lexicon
TypeExpr ::= TypeConsExpr |-> TypeExpr
TypeConsExpr ::= QTypeConstrID SimpleTypeExpr1 ... SimpleTypeExprn (n > 0)
| SimpleTypeExpr
SimpleTypeExpr ::= TypeVarID
| QTypeConstrID (unit type)
| () (tuple type, n > 1)
| [ TypeExpr ] (list type)
| ( TypeExpr ) (parenthesized type)
TypeVarID ::= see lexicon
FixityDeclaration ::= FixityKeyword Digit InfixOpID1, ..., InfixOpIDn (n > 0)
FixityKeyword ::= infixl | infi"x | infi
InfixOpID ::= see lexicon
FunctionDeclaration ::= Signature | External | Equat
External ::= FunctionNames external (externally defined functions)
Signature ::= FunctionNames :: TypeExpr
FunctionNames ::= FunctionName₁ \ldots \text{FunctionName}_n \quad (n > 0)

Equat ::= FunLHS = TypedExpr [\text{where} \text{LocalDefs}]
| FunLHS CondExprs [\text{where} \text{LocalDefs}]

FunLHS ::= FunctionName SimplePat₁ \ldots \text{SimplePat}_n \quad (n \geq 0)
| SimplePat InfixOpID SimplePat

CondExprs ::= |
| InfixExpr = TypedExpr [CondExprs]

Pattern ::= ConsPattern \ [QConsOp \ Pattern] \quad \text{(infix constructor pattern)}
ConsPattern ::= GDataConstr SimplePat₁ \ldots \text{SimplePat}_n
| SimplePat

SimplePat ::= Variable
| - \quad \text{(wildcard)}
| QDataConstr
| Literal
| - Int \quad \text{(negative pattern)}
| -. Float \quad \text{(negative float pattern)}
| () \quad \text{(empty tuple pattern)}
| ( Pattern₁ \ldots \text{Pattern}_n ) \quad (n > 1)
| ( Pattern ) \quad \text{(parenthesized pattern)}
| [ Pattern₁ \ldots \text{Pattern}_n ] \quad (n \geq 0)
| \text{Variable@SimplePat} \quad \text{(as-pattern)}
| ~ SimplePat \quad \text{(irrefutable pattern)}
| ( SimplePat QFunOp SimplePat ) \quad \text{(infix functional pattern)}
| ( QFunctionName SimplePat₁ \ldots \text{SimplePat}_n ) \quad \text{(functional pattern, }n > 0\text{)}
| QDataConstr \{ \text{FieldPat₁ \ldots FieldPat}_n \} \quad \text{(labeled pattern, }n \geq 0\text{)}

FieldPat ::= QLabelID = Pattern

QLabelID ::= see lexicon

LocalDefs ::= \{ \text{ValueDeclaration}_1 \ldots \text{ValueDeclaration}_n \} \quad (n > 0)

ValueDeclaration ::= FunctionDeclaration
| PatternDeclaration
| \text{VariableID₁ \ldots VariableID}_n \text{ free} \quad (n > 0)
| FixityDeclaration

PatternDeclaration ::= Pattern = TypedExpr [\text{where} \text{LocalDefs}]

TypedExpr ::= InfixExpr :: TypeExpr \quad \text{(expression type signature)}
| InfixExpr

InfixExpr ::= Expr QOp InfixExpr \quad \text{(infix operator application)}
| - InfixExpr \quad \text{(unary int minus)}
| -. InfixExpr \quad \text{(unary float minus)}
| Expr

Expr ::= \text{\lambda SimplePat₁ \ldots SimplePat}_n \to \text{TypedExpr} \quad \text{(lambda expression, }n > 0\text{)}
| \text{let LocalDefs in TypedExpr} \quad \text{(let expression)}
| \text{if TypedExpr then TypedExpr else TypedExpr} \quad \text{(conditional)}
| \text{case TypedExpr of }\{ \text{Alt₁ \ldots Alt}_n \} \quad \text{(case expression, }n \geq 0\text{)}
| \text{fcase TypedExpr of }\{ \text{Alt₁ \ldots Alt}_n \} \quad \text{(fcase expression, }n \geq 0\text{)}
| \text{do }\{ \text{Stmt₁ \ldots Stmt}_n ; \text{TypedExpr} \} \quad \text{(do expression, }n \geq 0\text{)}
| \text{FunctExpr}

FunctExpr ::= [\text{FunctExpr}] \text{BasicExpr} \quad \text{(function application)}

BasicExpr ::= QVariableID \quad \text{(variable)}
| - \quad \text{(anonymous free variable)}
QFunctionName 
| GDataConstr 
| Literal 
| (TypedExpr ) 
| (TypedExpr1 , ... , TypedExprn ) 
| [ TypedExpr1 , ... , TypedExprn ] 
| [ TypedExpr , TypedExpr ] . . [ TypedExpr ] 
| [ TypedExpr | Qual1 , ... , Qualn ] 
| ( InfixExpr QOp ) 
| ( QOp⟨-,-⟩ InfixExpr ) 
| QDataConstr { FBind1 , ... , FBindn } 
| BasicExpr⟨QDataConstr⟩ { FBind1 , ... , FBindn } 

Alt ::= Pattern -> TypedExpr [where LocalDefs] 
| Pattern GdAlts [where LocalDefs] 
GdAlts ::= | TypedExpr -> TypedExpr [GdAlts] 
FBind ::= QLabelID = TypedExpr 
Qual ::= TypedExpr 
| let LocalDefs 
| Pattern <- TypedExpr 
Stmt ::= TypedExpr 
| let LocalDefs 
| Pattern <- TypedExpr 

Literal ::= Int | Char | String | Float 
GDataConstr ::= () 
| [] 
| (,{},) 
| QDataConstr 

FunctionName ::= FunctionID | (InfixOpID) 
QFunctionName ::= QFunctionID | (QInfixOpID) 
Variable ::= VariableID | (InfixOpID) 
DataConstr ::= DataConstrID | (InfixOpID) 
QDataConstr ::= QDataConstrID | (QConsOp) 
QFunOp ::= QInfixOpID | ‘QFunctionID‘ 
ConsOp ::= InfixOpID | ‘DataConstrID‘ 
QOp ::= QFunOp | QConsOp 
QConsOp ::= GConSym | ‘QDataConstrID‘ 
GConSym ::= : | QInfixOpID 

27
5 CurryDoc: A Documentation Generator for Curry Programs

CurryDoc is a tool in the PAKCS distribution that generates the documentation for a Curry program (i.e., the main module and all its imported modules) in HTML format. The generated HTML pages contain information about all data types and functions exported by a module as well as links between the different entities. Furthermore, some information about the definitional status of functions (like rigid, flexible, external, complete, or overlapping definitions) are provided and combined with documentation comments provided by the programmer.

A documentation comment starts at the beginning of a line with “--- ” (also in literate programs!). All documentation comments immediately before a definition of a datatype or (top-level) function are kept together. The documentation comments for the complete module occur before the first “module” or “import” line in the module. The comments can also contain several special tags. These tags must be the first thing on its line (in the documentation comment) and continues until the next tag is encountered or until the end of the comment. The following tags are recognized:

@author comment

Specifies the author of a module (only reasonable in module comments).

@version comment

Specifies the version of a module (only reasonable in module comments).

@cons id comment

A comment for the constructor id of a datatype (only reasonable in datatype comments).

@param id comment

A comment for function parameter id (only reasonable in function comments). Due to pattern matching, this need not be the name of a parameter given in the declaration of the function but all parameters for this functions must be commented in left-to-right order (if they are commented at all).

@return comment

A comment for the return value of a function (only reasonable in function comments).

The comment of a documented entity can be any string in Markdown’s syntax (the currently supported set of elements is described in detail in the appendix). For instance, it can contain Markdown annotations for emphasizing elements (e.g., _verb_), strong elements (e.g., **important**), code elements (e.g., ‘3+4’), code blocks (lines prefixed by four blanks), unordered lists (lines prefixed by “ * ”), ordered lists (lines prefixed by blanks followed by a digit and a dot), quotations (lines prefixed by “> ”), and web links of the form “<http://...>” or “[link text](http://...)”. If the Markdown syntax should not be used, one could run CurryDoc with the parameter “--nomarkdown”.

The comments can also contain markups in HTML format so that special characters like “<” must be quoted (e.g., “&lt;”). However, header tags like <h1> should not be used since the structuring is generated by CurryDoc. In addition to Markdown or HTML markups, one can also mark

---

The documentation tool recognizes this association from the first identifier in a program line. If one wants to add a documentation comment to the definition of a function which is an infix operator, the first line of the operator definition should be a type definition, otherwise the documentation comment is not recognized.
references to names of operations or data types in Curry programs which are translated into links inside the generated HTML documentation. Such references have to be enclosed in single quotes. For instance, the text 'conc' refers to the Curry operation conc inside the current module whereas the text 'Prelude.reverse' refers to the operation reverse of the module Prelude. If one wants to write single quotes without this specific meaning, one can escape them with a backslash:

--- This is a comment without a 'reference'.

To simplify the writing of documentation comments, such escaping is only necessary for single words, i.e., if the text inside quotes has not the syntax of an identifier, the escaping can be omitted, as in

--- This isn’t a reference.

The following example text shows a Curry program with some documentation comments:

--- This is an example module.
--- @author Michael Hanus
--- @version 0.1

module Example where

--- The function 'conc' concatenates two lists.
--- @param xs - the first list
--- @param ys - the second list
--- @return a list containing all elements of 'xs' and 'ys'
conc [] ys = ys
conc (x:xs) ys = x : conc xs ys

--- The function 'last' computes the last element of a given list.
--- It is based on the operation 'conc' to concatenate two lists.
--- @param xs - the given input list
--- @return last element of the input list
last xs | conc ys [x] =:= xs = x where x,ys free

--- This data type defines _polymorphic_ trees.
--- @cons Leaf - a leaf of the tree
--- @cons Node - an inner node of the tree
data Tree a = Leaf a | Node [Tree a]

To generate the documentation, execute the command

currydoc Example

(currydoc is a command usually stored in pakcshome/bin where pakcshome is the installation directory of PAKCS; see Section 1.1). This command creates the directory DOC_Example (if it does not exist) and puts all HTML documentation files for the main program module Example and all its imported modules in this directory together with a main index file index.html. If one prefers another directory for the documentation files, one can also execute the command
currydoc docdir Example

where docdir is the directory for the documentation files.

In order to generate the common documentation for large collections of Curry modules (e.g., the libraries contained in the PAKCS distribution), one can call currydoc with the following options:

currydoc --noindexhtml docdir Mod : This command generates the documentation for module Mod in the directory docdir without the index pages (i.e., main index page and index pages for all functions and constructors defined in Mod and its imported modules).

currydoc --onlyindexhtml docdir Mod1 Mod2 ...Modn : This command generates only the index pages (i.e., a main index page and index pages for all functions and constructors defined in the modules Mod1, M2, ... ,Modn and their imported modules) in the directory docdir.
6 CurryBrowser: A Tool for Analyzing and Browsing Curry Programs

CurryBrowser is a tool to browse through the modules and functions of a Curry application, show them in various formats, and analyze their properties. Moreover, it is constructed in a way so that new analyzers can be easily connected to CurryBrowser. A detailed description of the ideas behind this tool can be found in [15, 16].

CurryBrowser is part of the PAKCS distribution and can be started in two ways:

- In the command shell via the command: `pakcs-home/bin/currybrowser mod`
- In the PAKCS environment after loading the module `mod` and typing the command `:browse`.

Here, `mod` is the name of the main module of a Curry application. After the start, CurryBrowser loads the interfaces of the main module and all imported modules before a GUI is created for interactive browsing.

To get an impression of the use of CurryBrowser, Figure 1 shows a snapshot of its use on a particular application (here: the implementation of CurryBrowser). The upper list box in the left column shows the modules and their imports in order to browse through the modules of an application. Similarly to directory browsers, the list of imported modules of a module can be opened or closed by clicking. After selecting a module in the list of modules, its source code, interface, or various other formats of the module can be shown in the main (right) text area. For instance, one can show pretty-printed versions of the intermediate flat programs (see below) in order to see how local function definitions are translated by lambda lifting [21] or pattern matching is translated into case expressions [11, 23]. Since Curry is a language with parametric polymorphism and type inference, programmers often omit the type signatures when defining functions. Therefore, one can also view (and store) the selected module as source code where missing type signatures are added.

Below the list box for selecting modules, there is a menu (“Analyze selected module”) to analyze all functions of the currently selected module at once. This is useful to spot some functions of a module that could be problematic in some application contexts, like functions that are impure (i.e., the result depends on the evaluation time) or partially defined (i.e., not evaluable on all ground terms). If such an analysis is selected, the names of all functions are shown in the lower list box of the left column (the “function list”) with prefixes indicating the properties of the individual functions.

The function list box can be also filled with functions via the menu “Select functions”. For instance, all functions or only the exported functions defined in the currently selected module can be shown there, or all functions from different modules that are directly or indirectly called from a currently selected function. This list box is central to focus on a function in the source code of some module or to analyze some function, i.e., showing their properties. In order to focus on a function, it is sufficient to check the “focus on code” button. To analyze an individually selected function, one can select an analysis from the list of available program analyses (through the menu “Select analysis”). In this case, the analysis results are either shown in the text box below the main text area or visualized by separate tools, e.g., by a graph drawing tool for visualizing call graphs. Some

---

4 Although CurryBrowser is implemented in Curry, some functionalities of it require an installed graph visualization tool (dot [http://www.graphviz.org/](http://www.graphviz.org/)), otherwise they have no effect.
analyses are local, i.e., they need only to consider the local definition of this function (e.g., “Calls directly,” “Overlapping rules,” “Pattern completeness”), where other analyses are global, i.e., they consider the definitions of all functions directly or indirectly called by this function (e.g., “Depends on,” “Solution complete,” “Set-valued”). Finally, there are a few additional tools integrated into CurryBrowser, for instance, to visualize the import relation between all modules as a dependency graph. These tools are available through the “Tools” menu.

More details about the use of CurryBrowser and all built-in analyses are available through the “Help” menu of CurryBrowser.
7 CurryTest: A Tool for Testing Curry Programs

CurryTest is a simple tool in the PAKCS distribution to write and run repeatable tests. CurryTest simplifies the task of writing test cases for a module and executing them. The tool is easy to use. Assume one has implemented a module `MyMod` and wants to write some test cases to test its functionality, making regression tests in future versions, etc. For this purpose, there is a system library `Assertion` (Section A.2.2) which contains the necessary definitions for writing tests. In particular, it exports an abstract polymorphic type “`Assertion a`” together with the following operations:

- `assertTrue :: String → Bool → Assertion ()`
- `assertEqual :: String → a → a → Assertion a`
- `assertValues :: String → a → [a] → Assertion a`
- `assertSolutions :: String → (a → Success) → [a] → Assertion a`
- `assertIO :: String → IO a → a → Assertion a`
- `assertEqualIO :: String → IO a → IO a → Assertion a`

The expression “`assertTrue s b`” is an assertion (named `s`) that the expression `b` has the value `True`. Similarly, the expression “`assertEqual s e1 e2`” asserts that the expressions `e1` and `e2` must be equal (i.e., `e1==e2` must hold), the expression “`assertValues s e vs`” asserts that `vs` is the multiset of all values of `e`, and the expression “`assertSolutions s c vs`” asserts that the constraint abstraction `c` has the multiset of solutions `vs`. Furthermore, the expression “`assertIO s a v`” asserts that the I/O action `a` yields the value `v` whenever it is executed, and the expression “`assertEqualIO s a1 a2`” asserts that the I/O actions `a1` and `a2` yield equal values. The name `s` provided as a first argument in each assertion is used in the protocol produced by the test tool.

One can define a test program by importing the module to be tested together with the module `Assertion` and defining top-level functions of type `Assertion` in this module (which must also be exported). As an example, consider the following program that can be used to test some list processing functions:

```haskell
import List
import Assertion

test1 = assertEqual "++" ([1,2]+[3,4]) [1,2,3,4]
test2 = assertTrue "all" (all (<5) [1,2,3,4])
test3 = assertSolutions "prefix" (\x → x++=:= [1,2]) [[],[1],[1,2]]
```

For instance, `test1` asserts that the result of evaluating the expression `([1,2]+[3,4])` is equal to `[1,2,3,4]`.

We can execute a test suite by the command

```
currytest TestList
```

(`currytest` is a program stored in `pakcshome/bin` where `pakcs home` is the installation directory of PAKCS; see Section 1.1). In our example, “`TestList.curry`” is the program containing the definition of all assertions. This has the effect that all exported top-level functions of type `Assertion` are
tested (i.e., the corresponding assertions are checked) and the results ("OK" or failure) are reported together with the name of each assertion. For our example above, we obtain the following successful protocol:

```
=====================================================================
Testing module "TestList"...
OK: ++
OK: all
OK: prefix
All tests successfully passed.
=====================================================================
```

There is also a graphical interface that summarizes the results more nicely. In order to start this interface, one has to add the parameter "--window" (or "-w"), e.g., executing a test suite by

`currytest --window TestList`

or

`currytest -w TestList`

A snapshot of the interface is shown in Figure 2.

---

5Due to a bug in older versions of SICStus-Prolog, it works only with SICStus-Prolog version 3.8.5 (or newer).
8 ERD2Curry: A Tool to Generate Programs from ER Specifications

ERD2Curry is a tool to generate Curry code to access and manipulate data persistently stored from entity relationship diagrams. The idea of this tool is described in detail in [10]. Thus, we describe only the basic steps to use this tool in the following.

If one creates an entity relationship diagram (ERD) with the Umbrello UML Modeller, one has to store its XML description in XMI format (as offered by Umbrello) in a file, e.g., “myerd.xmi”. This description can be compiled into a Curry program by the command

```
  erd2curry -x myerd.xmi
```

(erd2curry is a program stored in pakcs/home/bin where pakcs/home is the installation directory of PAKCS; see Section 1.1). If MyData is the name of the ERD, the Curry program file “MyData.curry” is generated containing all the necessary database access code as described in [10]. In addition to the generated Curry program file, two auxiliary program files ERDGeneric.curry and KeyDatabase.curry are created in the same directory.

If one does not want to use the Umbrello UML Modeller, which might be the preferred method since the interface to the Umbrello UML Modeller is no longer actively supported, one can also create a textual description of the ERD as a Curry term of type ERD (w.r.t. the type definition given in module pakcs/home/currytools/erd2curry/ERD.curry) and store it in some file, e.g., “myerd.term”. This description can be compiled into a Curry program by the command

```
  erd2curry -t myerd.term
```

The directory pakcs/home/currytools/erd2curry/ contains two examples for such ERD term files:

Blog.erdterm: This is a simple ERD model for a blog with entries, comments, and tags.

Uni.erdterm: This is an ERD model for university lectures as presented in the paper [10].

There is also the possibility to visualize an ERD term as a graph with the graph visualization program dotty (for this purpose, it might be necessary to adapt the definition of dotviewcommand in your “.pakcsrc” file, see Section 2.6, according to your local environment). The visualization can be performed by the command

```
  erd2curry -v myerd.term
```
9 Spicey: An ER-based Web Framework

Spicey is a framework to support the implementation of web-based systems in Curry. Spicey generates an initial implementation from an entity-relationship (ER) description of the underlying data. The generated implementation contains operations to create and manipulate entities of the data model, supports authentication, authorization, session handling, and the composition of individual operations to user processes. Furthermore, the implementation ensures the consistency of the database w.r.t. the data dependencies specified in the ER model, i.e., updates initiated by the user cannot lead to an inconsistent state of the database.

The idea of this tool, which is part of the distribution of PAKCS, is described in detail in [18]. Thus, we describe only the basic steps to use this tool in order to generate a web application.

First, one has to create a textual description of the entity-relationship model as a Curry term of type ERD (w.r.t. the type definitions given in module pakcs/home/currytools/erd2curry/ERD.curry) and store it in some file, e.g., “mymodel.erdterm”. The directory pakcs/home/currytools/spicey/ contains two examples for such ERD term files:

Blog.erdterm: This is a simple ER model for a blog with entries, comments, and tags, as presented in the paper [18].

Uni.erdterm: This is an ER model for university lectures as presented in the paper [10].

Then change to the directory in which you want to create the project sources. Execute the command

```
spiceup .../mymodel.erdterm
```

with the path to the ERD term file as a parameter (spiceup is a program stored in pakcs/home/bin where pakcs/home is the installation directory of PAKCS; see Section 1.1). You can also provide a path name, i.e., the name of a directory, where the database files should be stored, e.g.,

```
spiceup --dbpath DBDIR .../mymodel.erdterm
```

If the parameter “--dbpath DBDIR” is not provided, then DBDIR is set to the current directory (“.”). Since this specification will be used in the generated web programs, a relative database directory name will be relative to the place where the web programs are stored. In order to avoid such confusion, it might be better to specify an absolute path name for the database directory.

After the generation of this project (see the generated file README.txt for information about the generated project structure), one can compile the generated programs by

```
make compile
```

In order to generate the executable web application, configure the generated Makefile by adapting the variable WEBSERVERDIR to the location where the compiled cgi programs should be stored, and run

```
make deploy
```

After the successful compilation and deployment of all files, the application is executable in a web browser by selecting the URL `<URL of web dir>/spicey.cgi`.
10  UI: Declarative Programming of User Interfaces

The PAKCS distribution contains a collection of libraries to implement graphical user interfaces as well as web-based user interfaces from declarative descriptions. Exploiting these libraries, it is possible to define the structure and functionality of a user interface independent from the concrete technology. Thus, a graphical user interface or a web-based user interface can be generated from the same description by simply changing the imported libraries. This programming technique is described in detail in [17].

The libraries implementing these user interfaces are contained in the directory

\texttt{pakcshome/tools/ui}

Thus, in order to compile programs containing such user interface specifications, one has to include the directory \texttt{pakcshome/tools/ui} into the Curry load path (e.g., by setting the environment variable \texttt{CURRYPATH}, see also Section 1.3). The directory

\texttt{pakcshome/tools/ui/examples}

contains a few examples for such user interface specifications.
11 Preprocessing FlatCurry Files

After the invocation of the Curry front end to parse Curry programs and translate them into the intermediate FlatCurry representation, one can apply transformations on the FlatCurry files before they are passed to the back end which translates the FlatCurry files into Prolog code. These transformations are invoked by the FlatCurry preprocessor `pakcs/bin/fycpp`. Currently, only the FlatCurry file corresponding to the main module can be transformed.

A transformation can be specified as follows:

1. **Options to pakcs/bin/fcypp:**

   - `--fpopt`: Apply functional pattern optimization (see `pakcs/tools/optimize/NonStrictOpt.curry` for details).
   - `--compact`: Apply code compactification after parsing, i.e., transform the main module and all its imported into one module and delete all non-accessible functions.
   - `--compactexport`: Similar to `--compact` but delete all functions that are not accessible from the exported functions of the main module.
   - `--compactmain:f`: Similar to `--compact` but delete all functions that are not accessible from the function “f” of the main module.
   - `--fcypp cmd`: Apply command `cmd` to the main module after parsing. This is useful to integrate your own transformation into the compilation process. Note that the command “cmd prog” should perform a transformation on the FlatCurry file `prog.fcy`, i.e., it replaces the FlatCurry file by a new one.

2. **Setting the environment variable FCYPP:**

   For instance, setting FCYPP by
   ```
   export FCYPP="--fpopt"
   ```

   will apply the functional pattern optimization if programs are compiled and loaded in the PAKCS programming environment.

3. **Putting options into the source code:**

   If the source code contains a line with a comment of the form (the comment must start at the beginning of the line)
   ```
   {-# PAKCS_OPTION_FCYPP <options> #-}
   ```

   then the transformations specified by `<options>` are applied after translating the source code into FlatCurry code. For instance, the functional pattern optimization can be set by the comment
   ```
   {-# PAKCS_OPTION_FCYPP --fpopt #-}
   ```

   in the source code. Note that this comment must be in a single line of the source program. If there are multiple lines containing such comments, only the first one will be considered.
Multiple options: Note that an arbitrary number of transformations can be specified by the methods described above. If several specifications for preprocessing FlatCurry files are used, they are executed in the following order:

1. all transformations specified by the environment variable FCYPP (from left to right)
2. all transformations specified as command line options of fcyp (from left to right)
3. all transformations specified by a comment line in the source code (from left to right)
12 Technical Problems

Due to the fact that Curry is intended to implement distributed systems (see Appendix A.1.3), it might be possible that some technical problems arise due to the use of sockets for implementing these features. Therefore, this section gives some information about the technical requirements of PAKCS and how to solve problems due to these requirements.

There is one fixed port that is used by the implementation of PAKCS:

**Port 8766:** This port is used by the Curry Port Name Server (CPNS) to implement symbolic names for ports in Curry (see Appendix A.1.3). If some other process uses this port on the machine, the distribution facilities defined in the module *Ports* (see Appendix A.1.3) cannot be used.

If these features do not work, you can try to find out whether this port is in use by the shell command “`netstat -a | fgrep 8766`” (or similar).

The CPNS is implemented as a demon listening on its port 8766 in order to serve requests about registering a new symbolic name for a Curry port or asking the physical port number of a Curry port. The demon will be automatically started for the first time on a machine when a user compiles a program using Curry ports. It can also be manually started and terminated by the scripts `pakcs/home/cpns/start` and `pakcs/home/cpns/stop`. If the demon is already running, the command `pakcs/home/cpns/start` does nothing (so it can be always executed before invoking a Curry program using ports).

If you detect any further technical problem, please write to

pakcs@curry-language.org
References


A Libraries of the PAKCS Distribution

The PAKCS distribution comes with an extensive collection of libraries for application programming. The libraries for arithmetic constraints over real numbers, finite domain constraints, ports for concurrent and distributed programming, and meta-programming by representing Curry programs in Curry are described in the following subsection in more detail. The complete set of libraries with all exported types and functions are described in the further subsections. For a more detailed online documentation of all libraries of PAKCS, see http://www.informatik.uni-kiel.de/~pakcs/lib/index.html.

A.1 Constraints, Ports, Meta-Programming

A.1.1 Arithmetic Constraints

The primitive entities for the use of arithmetic constraints are defined in the system module CLPR (cf. Section 1.3), i.e., in order to use them, the program must contain the import declaration

import CLPR

Floating point arithmetic is supported in PAKCS via arithmetic constraints, i.e., the equational constraint “2.3 +. x =:= 5.5” is solved by binding x to 3.2 (rather than suspending the evaluation of the addition, as in corresponding constraints on integers like “3+x=:=5”). All operations related to floating point numbers are suffixed by “.”. The following functions and constraints on floating point numbers are supported in PAKCS:

(+.) :: Float -> Float -> Float
Addition on floating point numbers.

(-.) :: Float -> Float -> Float
Subtraction on floating point numbers.

(*.) :: Float -> Float -> Float
Multiplication on floating point numbers.

(/.) :: Float -> Float -> Float
Division on floating point numbers.

(<.) :: Float -> Float -> Success
Comparing two floating point numbers with the “less than” relation.

(>. ) :: Float -> Float -> Success
Comparing two floating point numbers with the “greater than” relation.

(<=.) :: Float -> Float -> Success
Comparing two floating point numbers with the “less than or equal” relation.

(>=.) :: Float -> Float -> Success
Comparing two floating point numbers with the “greater than or equal” relation.
i2f :: Int -> Float
    Converting an integer number into a floating point number.

As an example, consider a constraint mortgage which relates the principal p, the lifetime of the mortgage in months t, the monthly interest rate ir, the monthly repayment r, and the outstanding balance at the end of the lifetime b. The financial calculations can be defined by the following two rules in Curry (the second rule describes the repeated accumulation of the interest):

    import CLPR

    mortgage p t ir r b | t >. 0.0 \& t <=. 1.0 --lifetime not more than 1 month?
        = b :== p *:. (1.0 +. t *:. ir) -. t *:. r
    mortgage p t ir r b | t >. 1.0 --lifetime more than 1 month?
        = mortgage (p *:. (1.0+.ir)-.r) (t-.1.0) ir r b

Then we can calculate the monthly payment for paying back a loan of $100,000 in 15 years with a monthly interest rate of 1% by solving the goal

    mortgage 100000.0 180.0 0.01 r 0.0

which yields the solution r=1200.17.

Note that only linear arithmetic equalities or inequalities are solved by the constraint solver. Non-linear constraints like “x *:. x :== 4.0” are suspended until they become linear.

A.1.2 Finite Domain Constraints

Finite domain constraints are constraints where all variables can only take a finite number of possible values. For simplicity, the domain of finite domain variables are identified with a subset of the integers, i.e., the type of a finite domain variable is Int. The arithmetic operations related to finite domain variables are suffixed by “#”. The following functions and constraints for finite domain constraint solving are currently supported in PAKCS:6

    domain :: [Int] -> Int -> Int -> Success
        The constraint “domain [x_1,...,x_n] l u” is satisfied if the domain of all variables x_i is the interval [l, u].

    (+#) :: Int -> Int -> Int
        Addition on finite domain values.

    (-#) :: Int -> Int -> Int
        Subtraction on finite domain values.

    (*#) :: Int -> Int -> Int
        Multiplication on finite domain values.

    (#=) :: Int -> Int -> Success
        Equality of finite domain values.

6Note that this library is based on the corresponding library of SICStus-Prolog but does not implement the complete functionality of the SICStus-Prolog library. However, using the PAKCS interface for external functions (see Appendix E), it is relatively easy to provide the complete functionality.
These entities are defined in the system module CLPFD (cf. Section 1.3), i.e., in order to use it, the program must contain the import declaration

```
import CLPFD
```

As an example, consider the classical “send+more=money” problem where each letter must be replaced by a different digit such that this equation is valid and there are no leading zeros. The usual way to solve finite domain constraint problems is to specify the domain of the involved variables followed by a specification of the constraints and the labeling of the constraint variables in order to start the search for solutions. Thus, the “send+more=money” problem can be solved as follows:

```
import CLPFD

smm l =
l := [s,e,n,d,m,o,r,y] &
domain l 0 9 &
s ># 0 &
m ># 0 &
all_different l &

1000 *# s +# 100 *# e +# 10 *# n +# d +#
1000 *# m +# 100 *# o +# 10 *# r +# e =#
10000 *# m +# 1000 *# o +# 100 *# n +# 10 *# e +# y &
labeling [FirstFail] l
where s,e,n,d,m,o,r,y free

Then we can solve this problem by evaluating the goal “smm [s,e,n,d,m,o,r,y]” which yields the unique solution \{s=9,e=5,n=6,d=7,m=1,o=0,r=8,y=2\}.

### A.1.3 Ports: Distributed Programming in Curry

To support the development of concurrent and distributed applications, PAKCS supports internal and external ports as described in [12]. Since [12] contains a detailed description of this concept together with various programming examples, we only summarize here the functions and constraints supported for ports in PAKCS.

The basic datatypes, functions, and constraints for ports are defined in the system module Ports (cf. Section 1.3), i.e., in order to use ports, the program must contain the import declaration

```
import Ports
```

This declaration includes the following entities in the program:

**Port a**

This is the datatype of a port to which one can send messages of type a.

**openPort :: Port a -> [a] -> Success**

The constraint “openPort p s” establishes a new internal port p with an associated message stream s. p and s must be unbound variables, otherwise the constraint fails (and causes a runtime error).

**send :: a -> Port a -> Success**

The constraint “send m p” is satisfied if p is constrained to contain the message m, i.e., m will be sent to the port p so that it appears in the corresponding stream.

**doSend :: a -> Port a -> IO ()**

The I/O action “doSend m p” solves the constraint “send m p” and returns nothing.

**openNamedPort :: String -> IO [a]**

The I/O action “openNamedPort n” opens a new external port with symbolic name n and returns the associated stream of messages.

**connectPort :: String -> IO (Port a)**

The I/O action “connectPort n” returns a port with symbolic name n (i.e., n must have the form “portname@machine”) to which one can send messages by the send constraint. Currently,
no dynamic type checking is done for external ports, i.e., sending messages of the wrong type to a port might lead to a failure of the receiver.

**Restrictions:** Every expression, possibly containing logical variables, can be sent to a port. However, as discussed in [12], port communication is strict, i.e., the expression is evaluated to normal form before sending it by the constraint `send`. Furthermore, if messages containing logical variables are sent to external ports, the behavior is as follows:

1. The sender waits until all logical variables in the message have been bound by the receiver.

2. The binding of a logical variable received by a process is sent back to the sender of this logical variable only if it is bound to a ground term, i.e., as long as the binding contains logical variables, the sender is not informed about the binding and, therefore, the sender waits.

**External ports on local machines:** The implementation of external ports assumes that the host machine running the application is connected to the Internet (i.e., it uses the standard IP address of the host machine for message sending). If this is not the case and the application should be tested by using external ports only on the local host without a connection to the Internet, the environment variable “PAKCS_LOCALHOST” must be set to “yes” before PAKCS is started. In this case, the IP address 127.0.0.1 and the hostname “localhost” are used for identifying the local machine.

**Selection of Unix sockets for external ports:** The implementation of ports uses sockets to communicate messages sent to external ports. Thus, if a Curry program uses the I/O action `openNamedPort` to establish an externally visible server, PAKCS selects a Unix socket for the port communication. Usually, a free socket is selected by the operating system. If the socket number should be fixed in an application (e.g., because of the use of firewalls that allow only communication over particular sockets), then one can set the environment variable “PAKCS_SOCKET” to a distinguished socket number before PAKCS is started. This has the effect that PAKCS uses only this socket number for communication (even for several external ports used in the same application program).

**Debugging:** To debug distributed systems, it is sometimes helpful to see all messages sent to external ports. This is supported by the environment variable “PAKCS_TRACEPORTS”. If this variable is set to “yes” before PAKCS is started, then all connections to external ports and all messages sent and received on external ports are printed on the standard error stream.

**A.1.4 AbstractCurry and FlatCurry: Meta-Programming in Curry**

To support meta-programming, i.e., the manipulation of Curry programs in Curry, there are system modules FlatCurry and AbstractCurry (stored in the directory “pakcs/home/1ib/meta”) which define datatypes for the representation of Curry programs. AbstractCurry is a more direct representation of a Curry program, whereas FlatCurry is a simplified representation where local function definitions are replaced by global definitions (i.e., lambda lifting has been performed) and pattern matching
is translated into explicit case/or expressions. Thus, FlatCurry can be used for more back-end oriented program manipulations (or, for writing new back ends for Curry), whereas AbstractCurry is intended for manipulations of programs that are more oriented towards the source program. Both modules contain predefined I/O actions to read programs in the AbstractCurry (readCurry) or FlatCurry (readFlatCurry) format. These actions parse the corresponding source program and return a data term representing this program (according to the definitions in the modules AbstractCurry and FlatCurry).

Since all datatypes are explained in detail in these modules, we refer to the online documentation of these modules.

As an example, consider a program file “test.curry” containing the following two lines:

\[
\begin{align*}
\text{rev} \ [] &= [] \\
\text{rev} \ (x:xs) &= (\text{rev} \ xs) ++ [x]
\end{align*}
\]

Then the I/O action (FlatCurry.readFlatCurry "test") returns the following term:

\[
\begin{align*}
\text{(Prog "test" \\
\text{"Prelude"}] \\
[] \\
\text{[Func \ ("test","rev") 1 Public \\
\text{ (FuncType \ (TCons \ ("Prelude","[]") \ [(TVar \ 0)]) \\
\text{ (TCons \ ("Prelude","[]") \ [(TVar \ 0)])})
\text{(Rule [0] \\
\text{ (Case Flex \ (Var \ 1) \\
\text{ [Branch \ (Pattern \ ("Prelude","[]") \ []) \\
\text{ (Comb \ ConsCall \ ("Prelude","[]") \ []), \\
\text{ Branch \ (Pattern \ ("Prelude",:"\) \ [2,3]) \\
\text{ (Comb \ FuncCall \ ("Prelude","++") \\
\text{ [Comb \ FuncCall \ ("test","rev") \ [Var \ 3], \\
\text{ Comb \ ConsCall \ ("Prelude",:"\) \\
\text{ [Var \ 2,Comb \ ConsCall \ ("Prelude","[]") \ []]}}
\text{ ]})]) \\
\text{ []} \\
\text{ )})})}])}
\end{align*}
\]

A.2 General Libraries
A.2.1 Library AllSolutions

This module contains a collection of functions for obtaining lists of solutions to constraints. These operations are useful to encapsulate non-deterministic operations between I/O actions in order to connects the worlds of logic and functional programming and to avoid non-determinism failures on the I/O level.

In contrast the "old" concept of encapsulated search (which could be applied to any subexpression in a computation), the operations to encapsulate search in this module are I/O actions in order to

\[\text{http://www.informatik.uni-kiel.de/~pakcs/lib/CDOC/FlatCurry.html and http://www.informatik.uni-kiel.de/~pakcs/lib/CDOC/AbstractCurry.html}\]
avoid some anomalies in the old concept.

**Exported types:**

```haskell
data SearchTree

A search tree for representing search structures.
```

**Exported constructors:**

- `SearchBranch :: [(b,SearchTree a b)] → SearchTree a b`
- `Solutions :: [a] → SearchTree a b`

**Exported functions:**

- `getAllSolutions :: (a → Success) → IO [a]`

  Gets all solutions to a constraint (currently, via an incomplete depth-first left-to-right strategy). Conceptually, all solutions are computed on a copy of the constraint, i.e., the evaluation of the constraint does not share any results. Moreover, this evaluation suspends if the constraints contain unbound variables. Similar to Prolog's `findall`.

- `getAllValues :: a → IO [a]`

  Gets all values of an expression. Since this is based on `getAllSolutions`, it inherits the same restrictions.

- `getOneSolution :: (a → Success) → IO (Maybe a)`

  Gets one solution to a constraint (currently, via an incomplete left-to-right strategy). Returns Nothing if the search space is finitely failed.

- `getOneValue :: a → IO (Maybe a)`

  Gets one value of an expression (currently, via an incomplete left-to-right strategy). Returns Nothing if the search space is finitely failed.

- `getAllFailures :: a → (a → Success) → IO [a]`

  Returns a list of values that do not satisfy a given constraint.

- `getSearchTree :: [a] → (b → Success) → IO (SearchTree b a)`

  Computes a tree of solutions where the first argument determines the branching level of the tree. For each element in the list of the first argument, the search tree contains a branch node with a child tree for each value of this element. Moreover, evaluations of elements in the branch list are shared within corresponding subtrees.

**A.2.2 Library Assertion**

This module defines the datatype and operations for the Curry module tester "currytest".
Exported types:

data Assertion

    Datatype for defining test cases.

Exported constructors:

data ProtocolMsg

    The messages sent to the test GUI. Used by the currytest tool.

Exported constructors:

  • TestModule :: String → ProtocolMsg
  • TestCase :: String → Bool → ProtocolMsg
  • TestFinished :: ProtocolMsg
  • TestCompileError :: ProtocolMsg

Exported functions:

assertTrue :: String → Bool → Assertion ()

    (assertTrue s b) asserts (with name s) that b must be true.

assertEqual :: String → a → a → Assertion a

    (assertEqual s e1 e2) asserts (with name s) that e1 and e2 must be equal (w.r.t. ==).

assertValues :: String → a → [a] → Assertion a

    (assertValues s e vs) asserts (with name s) that vs is the multiset of all values of e. All values of e are compared with the elements in vs w.r.t. ==.

assertSolutions :: String → (a → Success) → [a] → Assertion a

    (assertSolutions s c vs) asserts (with name s) that constraint abstraction c has the multiset of solutions vs. The solutions of c are compared with the elements in vs w.r.t. ==.

assertIO :: String → IO a → a → Assertion a

    (assertIO s a r) asserts (with name s) that I/O action a yields the result value r.

assertEqualIO :: String → IO a → IO a → Assertion a

    (assertEqualIO s a1 a2) asserts (with name s) that I/O actions a1 and a2 yield equal (w.r.t. ==) results.
seqStrActions :: IO (String,Bool) → IO (String,Bool) → IO (String,Bool)

Combines two actions and combines their results. Used by the currytest tool.

checkAssertion :: String → ((String,Bool) → IO (String,Bool)) → Assertion a → IO (String,Bool)

Executes and checks an assertion, and process the result by an I/O action. Used by the currytest tool.

writeAssertResult :: (String,Bool) → IO Int

Prints the results of assertion checking. If failures occurred, the return code is positive. Used by the currytest tool.

showTestMod :: Int → String → IO ()

Sends message to GUI for showing test of a module. Used by the currytest tool.

showTestCase :: Int → (String,Bool) → IO (String,Bool)

Sends message to GUI for showing result of executing a test case. Used by the currytest tool.

showTestEnd :: Int → IO ()

Sends message to GUI for showing end of module test. Used by the currytest tool.

showTestCompileError :: Int → IO ()

Sends message to GUI for showing compilation errors in a module test. Used by the currytest tool.

A.2.3 Library Char

Library with some useful functions on characters.

Exported functions:

isAscii :: Char → Bool

Returns true if the argument is an ASCII character.

isLatin1 :: Char → Bool

Returns true if the argument is an Latin-1 character.

isAsciiLower :: Char → Bool

Returns true if the argument is an ASCII lowercase letter.

isAsciiUpper :: Char → Bool

Returns true if the argument is an ASCII uppercase letter.
isControl :: Char → Bool
    Returns true if the argument is a control character.

isUpper :: Char → Bool
    Returns true if the argument is an uppercase letter.

isLower :: Char → Bool
    Returns true if the argument is a lowercase letter.

isAlpha :: Char → Bool
    Returns true if the argument is a letter.

isDigit :: Char → Bool
    Returns true if the argument is a decimal digit.

isAlphaNum :: Char → Bool
    Returns true if the argument is a letter or digit.

isBinDigit :: Char → Bool
    Returns true if the argument is a binary digit.

isOctDigit :: Char → Bool
    Returns true if the argument is an octal digit.

isHexDigit :: Char → Bool
    Returns true if the argument is a hexadecimal digit.

isSpace :: Char → Bool
    Returns true if the argument is a white space.

toUpper :: Char → Char
    Converts lowercase into uppercase letters.

toLower :: Char → Char
    Converts uppercase into lowercase letters.

digitToInt :: Char → Int
    Converts a (hexadecimal) digit character into an integer.

intToDigit :: Int → Char
    Converts an integer into a (hexadecimal) digit character.
A.2.4 Library CHR

A representation of CHR rules in Curry, an interpreter for CHR rules based on the refined operational semantics of Duck et al. (ICLP 2004), and a compiler into CHR(Prolog).

To use CHR(Curry), specify the CHR(Curry) rules in a Curry program, load it, add module CHR and interpret or compile the rules with runCHR or compileCHR, respectively. This can be done in one shot with

> pakcs :l MyRules :add CHR :eval 'compileCHR "MyCHR" [rule1,rule2]' :q

Exported types:

data CHR

   The basic data type of Constraint Handling Rules.

Exported constructors:

data Goal

   A CHR goal is a list of CHR constraints (primitive or user-defined).

Exported constructors:

Exported functions:

(<=>) :: Goal a b → Goal a b → CHR a b

   Simplification rule.

==(>) :: Goal a b → Goal a b → CHR a b

   Propagation rule.

(\) :: Goal a b → CHR a b → CHR a b

   Simpagation rule: if rule is applicable, the first constraint is kept and the second constraint is deleted.

(|>) :: CHR a b → Goal a b → CHR a b

   A rule with a guard.

(/\) :: Goal a b → Goal a b → Goal a b

   Conjunction of CHR goals.

true :: Goal a b

   The always satisfiable CHR constraint.

fail :: Goal a b
The always failing constraint.

\textbf{andCHR} :: [\text{Goal} \ a \ b] \rightarrow \text{Goal} \ a \ b

Join a list of CHR goals into a single CHR goal (by conjunction).

\textbf{allCHR} :: (a \rightarrow \text{Goal} \ b \ c) \\rightarrow [a] \rightarrow \text{Goal} \ b \ c

Is a given constraint abstraction satisfied by all elements in a list?

\textbf{chrsToGoal} :: [a] \rightarrow \text{Goal} \ b \ a

Transforms a list of CHR constraints into a CHR goal.

\textbf{toGoal1} :: (a \rightarrow b) \rightarrow a \rightarrow \text{Goal} \ c \ b

Transform unary CHR constraint into a CHR goal.

\textbf{toGoal2} :: (a \rightarrow b \rightarrow c) \rightarrow a \rightarrow b \rightarrow \text{Goal} \ d \ c

Transforms binary CHR constraint into a CHR goal.

\textbf{toGoal3} :: (a \rightarrow b \rightarrow c \rightarrow d) \rightarrow a \rightarrow b \rightarrow c \rightarrow \text{Goal} \ e \ d

Transforms a ternary CHR constraint into a CHR goal.

\textbf{toGoal4} :: (a \rightarrow b \rightarrow c \rightarrow d \rightarrow e \rightarrow e) \rightarrow a \rightarrow b \rightarrow c \rightarrow d \rightarrow e \rightarrow \text{Goal} \ f \ e

Transforms a CHR constraint of arity 4 into a CHR goal.

\textbf{toGoal5} :: (a \rightarrow b \rightarrow c \rightarrow d \rightarrow e \rightarrow f) \rightarrow a \rightarrow b \rightarrow c \rightarrow d \rightarrow e \rightarrow \text{Goal} \ g \ f

Transforms a CHR constraint of arity 5 into a CHR goal.

\textbf{toGoal6} :: (a \rightarrow b \rightarrow c \rightarrow d \rightarrow e \rightarrow f \rightarrow g) \rightarrow a \rightarrow b \rightarrow c \rightarrow d \rightarrow e \rightarrow f \rightarrow \text{Goal} \ h \ g

Transforms a CHR constraint of arity 6 into a CHR goal.

\textbf{(.=.)} :: a \rightarrow a \rightarrow \text{Goal} \ a \ b

Primitive syntactic equality on arbitrary terms.

\textbf{(./=.)} :: a \rightarrow a \rightarrow \text{Goal} \ a \ b

Primitive syntactic disequality on ground(!) terms.

\textbf{(.<=.)} :: a \rightarrow a \rightarrow \text{Goal} \ a \ b

Primitive less-or-equal constraint.

\textbf{(.>=.)} :: a \rightarrow a \rightarrow \text{Goal} \ a \ b

Primitive greater-or-equal constraint.

\textbf{(.<.)} :: a \rightarrow a \rightarrow \text{Goal} \ a \ b
Primitive less-than constraint.

\( (>.) : a \to a \to \text{Goal} a b \)

Primitive greater-than constraint.

ground \( : a \to \text{Goal} a b \)

Primitive groundness constraint (useful for guards).

nonvar \( : a \to \text{Goal} a b \)

Primitive nonvar constraint (useful for guards).

anyPrim \( : (\_ \to \text{Success}) \to \text{Goal} a b \)

Embed user-defined primitive constraint.

solveCHR \( : [a] \to \text{CHR} a b \to \text{Goal} a b \to \text{Success} \)

Interpret CHR rules (parameterized over domain variables) for a given CHR goal (second argument) and embed this as a constraint solver in Curry. If user-defined CHR constraints remain after applying all CHR rules, a warning showing the residual constraints is issued.

runCHR \( : [a] \to \text{CHR} a b \to \text{Goal} a b \to [b] \)

Interpret CHR rules (parameterized over domain variables) for a given CHR goal (second argument) and return the remaining CHR constraints.

runCHRwithTrace \( : [a] \to \text{CHR} a b \to \text{Goal} a b \to [b] \)

Interpret CHR rules (parameterized over domain variables) for a given CHR goal (second argument) and return the remaining CHR constraints. Trace also the active and passive constraints as well as the applied rule number during computation.

compileCHR \( : \text{String} \to [a] \to \text{CHR} a b \to \text{IO} () \)

Compile a list of CHR(Curry) rules into CHR(Prolog) and store its interface in a Curry program (name given as first argument).

chr2success \( : \text{Goal} a b \to \text{Success} \)

Transforms a primitive CHR constraint into a Curry constraint. Used in the generated CHR(Prolog) code to evaluated primitive constraints.

A.2.5 Library CHRcompiled

This module defines the structure of CHR goals and some constructors to be used in compiled CHR(Curry) rules. Furthermore, it defines an operation solveCHR to solve a CHR goal as a constraint.

This module is imported in compiled CHR(Curry) programs, compare library CHR.
Exported types:

data Goal

A typed CHR goal. Since types are not present at run-time in compiled, we use a
phantom type to parameterize goals over CHR constraints. The argument of the goal
is the constraint implementing the goal with the compiled CHR(Prolog) program.

Exported constructors:

- Goal :: Success → Goal a

Exported functions:

(/
\) :: Goal a → Goal a → Goal a

Conjunction of CHR goals.

true :: Goal a

The always satisfiable CHR constraint.

fail :: Goal a

The always failing constraint.

andCHR :: [Goal a] → Goal a

Join a list of CHR goals into a single CHR goal (by conjunction).

allCHR :: (a → Goal b) → [a] → Goal b

Is a given constraint abstraction satisfied by all elements in a list?

solveCHR :: Goal a → Success

Evaluate a given CHR goal and embed this as a constraint in Curry. Note: due to limi-
tations of the CHR(Prolog) implementation, no warning is issued if residual constraints
remain after the evaluation.

warnSuspendedConstraints :: Bool → Success

Primitive operation that issues a warning if there are some suspended constraints in
the CHR constraint store. If the argument is true, then all suspended constraints are
shown, otherwise only the first one.
A.2.6 Library CLPFD

Library for finite domain constraint solving.
The general structure of a specification of an FD problem is as follows:
\[
\text{domain} \ \text{constraint} \ & \ \text{fd\_constraint} \ \& \ \text{labeling}
\]
where:
\text{domain\_constraint} specifies the possible range of the FD variables (see constraint \text{domain})
\text{fd\_constraint} specifies the constraint to be satisfied by a valid solution (see constraints #+, #-, allDifferent, etc below)
\text{labeling} is a labeling function to search for a concrete solution.
Note: This library is based on the corresponding library of Sicstus-Prolog but does not implement
the complete functionality of the Sicstus-Prolog library. However, using the PAKCS interface for
external functions, it is relatively easy to provide the complete functionality.

Exported types:

\text{data Constraint}

A datatype to represent reifyable constraints.

\text{Exported constructors:}

\text{data LabelingOption}

This datatype contains all options to control the instantiated of FD variables with the
enumeration constraint \text{labeling}.

\text{Exported constructors:}

- \text{LeftMost :: LabelingOption}
  
  \text{LeftMost}
  
  - The leftmost variable is selected for instantiation (default)

- \text{FirstFail :: LabelingOption}
  
  \text{FirstFail}
  
  - The leftmost variable with the smallest domain is selected (also known as first-fail prin-
  ciple)

- \text{FirstFailConstrained :: LabelingOption}
  
  \text{FirstFailConstrained}
  
  - The leftmost variable with the smallest domain and the most constraints on it is selected.

- \text{Min :: LabelingOption}
  
  \text{Min}
  
  - The leftmost variable with the smalled lower bound is selected.
• **Max** :: LabelingOption
  
  Max
  
  – The leftmost variable with the greatest upper bound is selected.

• **Step** :: LabelingOption
  
  Step
  
  – Make a binary choice between $x=b$ and $x\neq b$ for the selected variable $x$ where $b$ is the lower or upper bound of $x$ (default).

• **Enum** :: LabelingOption
  
  Enum
  
  – Make a multiple choice for the selected variable for all the values in its domain.

• **Bisect** :: LabelingOption
  
  Bisect
  
  – Make a binary choice between $x\leq m$ and $x\geq m$ for the selected variable $x$ where $m$ is the midpoint of the domain $x$ (also known as domain splitting).

• **Up** :: LabelingOption
  
  Up
  
  – The domain is explored for instantiation in ascending order (default).

• **Down** :: LabelingOption
  
  Down
  
  – The domain is explored for instantiation in descending order.

• **All** :: LabelingOption
  
  All
  
  – Enumerate all solutions by backtracking (default).

• **Minimize** :: Int → LabelingOption
  
  Minimize $v$
  
  – Find a solution that minimizes the domain variable $v$ (using a branch-and-bound algorithm).

• **Maximize** :: Int → LabelingOption
  
  Maximize $v$
  
  – Find a solution that maximizes the domain variable $v$ (using a branch-and-bound algorithm).
• **Assumptions :: Int → LabelingOption**

  Assumptions x

  - The variable x is unified with the number of choices made by the selected enumeration strategy when a solution is found.

**Exported functions:**

domain :: [Int] → Int → Int → Success

  Constraint to specify the domain of all finite domain variables.

(+#) :: Int → Int → Int

  Addition of FD variables.

(-#) :: Int → Int → Int

  Subtraction of FD variables.

(*#) :: Int → Int → Int

  Multiplication of FD variables.

(=#) :: Int → Int → Success

  Equality of FD variables.

(/=#) :: Int → Int → Success

  Disequality of FD variables.

(<#) :: Int → Int → Success

  "Less than" constraint on FD variables.

(<=#) :: Int → Int → Success

  "Less than or equal" constraint on FD variables.

(>#) :: Int → Int → Success

  "Greater than" constraint on FD variables.

(>=#) :: Int → Int → Success

  "Greater than or equal" constraint on FD variables.

(#=#) :: Int → Int → Constraint

  Reifiable equality constraint on FD variables.

(#/=#) :: Int → Int → Constraint

  Reifiable inequality constraint on FD variables.
(\#\lt\#) :: Int \to Int \to Constraint

Reifiable "less than" constraint on FD variables.

(\#\leq\#) :: Int \to Int \to Constraint

Reifiable "less than or equal" constraint on FD variables.

(\#\gt\#) :: Int \to Int \to Constraint

Reifiable "greater than" constraint on FD variables.

(\#\geq\#) :: Int \to Int \to Constraint

Reifiable "greater than or equal" constraint on FD variables.

neg :: Constraint \to Constraint

The resulting constraint is satisfied if both argument constraints are satisfied.

(\#/\#) :: Constraint \to Constraint \to Constraint

The resulting constraint is satisfied if both argument constraints are satisfied.

(\#/\#) :: Constraint \to Constraint \to Constraint

The resulting constraint is satisfied if both argument constraints are satisfied.

(\#\geq\#) :: Constraint \to Constraint \to Constraint

The resulting constraint is satisfied if the first argument constraint do not hold or both argument constraints are satisfied.

(\#\leq\#) :: Constraint \to Constraint \to Constraint

The resulting constraint is satisfied if both argument constraint are either satisfied and do not hold.

solve :: Constraint \to Success

Solves a reified constraint.

sum :: [Int] \to (Int \to Int \to Success) \to Int \to Success

Relates the sum of FD variables with some integer of FD variable.

scalarProduct :: [Int] \to [Int] \to (Int \to Int \to Success) \to Int \to Success

(scalarProduct cs vs relop v) is satisfied if ((cs*vs) relop v) is satisfied. The first argument must be a list of integers. The other arguments are as in sum.

count :: Int \to [Int] \to (Int \to Int \to Success) \to Int \to Success

(count v vs relop c) is satisfied if (n relop c), where n is the number of elements in the list of FD variables vs that are equal to v, is satisfied. The first argument must be an integer. The other arguments are as in sum.
allDifferent :: [Int] → Success

"All different" constraint on FD variables.

allDifferent :: [Int] → Success

For backward compatibility. Use allDifferent.

indomain :: Int → Success

Instantiate a single FD variable to its values in the specified domain.

labeling :: [LabelingOption] → [Int] → Success

Instantiate FD variables to their values in the specified domain.

A.2.7 Library CLPR

Library for constraint programming with arithmetic constraints over reals.

Exported functions:

(+) :: Float → Float → Float

Addition on floats in arithmetic constraints.

(-) :: Float → Float → Float

Subtraction on floats in arithmetic constraints.

(*) :: Float → Float → Float

Multiplication on floats in arithmetic constraints.

(/) :: Float → Float → Float

Division on floats in arithmetic constraints.

(<) :: Float → Float → Success

"Less than" constraint on floats.

(>) :: Float → Float → Success

"Greater than" constraint on floats.

(<=) :: Float → Float → Success

"Less than or equal" constraint on floats.

(>=) :: Float → Float → Success

"Greater than or equal" constraint on floats.

i2f :: Int → Float
Conversion function from integers to floats. Rigid in the first argument, i.e., suspends until the first argument is ground.

\[
\text{minimumFor} :: (a \to \text{Success}) \to (a \to \text{Float}) \to a
\]

Computes the minimum with respect to a given constraint. \((\text{minimumFor } g f)\) evaluates to \(x\) if \((g x)\) is satisfied and \((f x)\) is minimal. The evaluation fails if such a minimal value does not exist. The evaluation suspends if it contains unbound non-local variables.

\[
\text{minimize} :: (a \to \text{Success}) \to (a \to \text{Float}) \to a \to \text{Success}
\]

Minimization constraint. \((\text{minimize } g f x)\) is satisfied if \((g x)\) is satisfied and \((f x)\) is minimal. The evaluation suspends if it contains unbound non-local variables.

\[
\text{maximumFor} :: (a \to \text{Success}) \to (a \to \text{Float}) \to a
\]

Computes the maximum with respect to a given constraint. \((\text{maximumFor } g f)\) evaluates to \(x\) if \((g x)\) is satisfied and \((f x)\) is maximal. The evaluation fails if such a maximal value does not exist. The evaluation suspends if it contains unbound non-local variables.

\[
\text{maximize} :: (a \to \text{Success}) \to (a \to \text{Float}) \to a \to \text{Success}
\]

Maximization constraint. \((\text{maximize } g f x)\) is satisfied if \((g x)\) is satisfied and \((f x)\) is maximal. The evaluation suspends if it contains unbound non-local variables.

### A.2.8 Library CLPB

This library provides a Boolean Constraint Solver based on BDDs.

**Exported types:**

\[
data \text{Boolean}
\]

**Exported constructors:**

**Exported functions:**

\[
\text{true} :: \text{Boolean}
\]

The always satisfied constraint

\[
\text{false} :: \text{Boolean}
\]

The never satisfied constraint

\[
\text{neg} :: \text{Boolean} \to \text{Boolean}
\]

Result is true iff argument is false.

\[
(\&\&) :: \text{Boolean} \to \text{Boolean} \to \text{Boolean}
\]
Result is true iff both arguments are true.

(||) :: Boolean → Boolean → Boolean

Result is true iff at least one argument is true.

(./=) :: Boolean → Boolean → Boolean

Result is true iff exactly one argument is true.

(==) :: Boolean → Boolean → Boolean

Result is true iff both arguments are equal.

(<=) :: Boolean → Boolean → Boolean

Result is true iff the first argument implies the second.

(>=) :: Boolean → Boolean → Boolean

Result is true iff the second argument implies the first.

(<) :: Boolean → Boolean → Boolean

Result is true iff the first argument is false and the second is true.

(>) :: Boolean → Boolean → Boolean

Result is true iff the first argument is true and the second is false.

count :: [Boolean] → [Int] → Boolean

Result is true iff the count of valid constraints in the first list is an element of the second list.

exists :: Boolean → Boolean → Boolean

Result is true, if the first argument is a variable which can be instantiated such that the second argument is true.

satisfied :: Boolean → Success

Checks the consistency of the constraint with regard to the accumulated constraints, and, if the check succeeds, tells the constraint.

check :: Boolean → Bool

Asks whether the argument (or its negation) is now entailed by the accumulated constraints. Fails if it is not.

bound :: [Boolean] → Success

Instantiates given variables with regard to the accumulated constraints.

simplify :: Boolean → Boolean

Simplifies the argument with regard to the accumulated constraints.

evaluate :: Boolean → Bool

Evaluates the argument with regard to the accumulated constraints.
A.2.9 Library Combinatorial

A collection of common non-deterministic and/or combinatorial operations. Many operations are intended to operate on sets. The representation of these sets is not hidden; rather sets are represented as lists. Ideally these lists contains no duplicate elements and the order of their elements cannot be observed. In practice, these conditions are not enforced.

Exported functions:

permute :: [a] → [a]

Compute any permutation of a list. For example, [1,2,3,4] may give [1,3,4,2].

subset :: [a] → [a]

Compute any sublist of a list. The sublist contains some of the elements of the list in the same order. For example, [1,2,3,4] may give [1,3], and [1,2,3] gives [1,2],[1,3],[1],[2,3],[2],[3], or [].

splitSet :: [a] → ([a],[a])

Split a list into any two sublists. For example, [1,2,3,4] may give ([1,3,4],[2]).

sizedSubset :: Int → [a] → [a]

Compute any sublist of fixed length of a list. Similar to subset, but the length of the result is fixed.

partition :: [a] → [[a]]

Compute any partition of a list. The output is a list of non-empty lists such that their concatenation is a permutation of the input list. No guarantee is made on the order of the arguments in the output. For example, [1,2,3,4] may give [[4],[2,3],[1]], and [1,2,3] gives [[1,2,3],[[2,3],[1]], [[1,3],[2]], [[3],[1,2]], or [[3],[2],[1]].

A.2.10 Library Constraint

Some useful operations for constraint programming.

Exported functions:

(<:) :: a → a → Success

Less-than on ground data terms as a constraint.

(>:) :: a → a → Success

Greater-than on ground data terms as a constraint.

(<=:) :: a → a → Success

Less-or-equal on ground data terms as a constraint.
\( (\geq:) :: a \rightarrow a \rightarrow \text{Success} \)
Greater-or-equal on ground data terms as a constraint.

\( \text{andC} :: [\text{Success}] \rightarrow \text{Success} \)
Evaluates the conjunction of a list of constraints.

\( \text{orC} :: [\text{Success}] \rightarrow \text{Success} \)
Evaluates the disjunction of a list of constraints.

\( \text{allC} :: (a \rightarrow \text{Success}) \rightarrow [a] \rightarrow \text{Success} \)
Is a given constraint abstraction satisfied by all elements in a list?

\( \text{anyC} :: (a \rightarrow \text{Success}) \rightarrow [a] \rightarrow \text{Success} \)
Is there an element in a list satisfying a given constraint?

### A.2.11 Library CPNS
Implementation of a Curry Port Name Server based on raw sockets. It is used to implement the library Ports for distributed programming with ports.

**Exported functions:**

\( \text{cpnsStart} :: \text{IO} () \)
Starts the "Curry Port Name Server" (CPNS) running on the local machine. The CPNS is responsible to resolve symbolic names for ports into physical socket numbers so that a port can be reached under its symbolic name from any machine in the world.

\( \text{cpnsShow} :: \text{IO} () \)
Shows all registered ports at the local CPNS demon (in its logfile).

\( \text{cpnsStop} :: \text{IO} () \)
Terminates the local CPNS demon

\( \text{registerPort} :: \text{String} \rightarrow \text{Int} \rightarrow \text{Int} \rightarrow \text{IO} () \)
Registers a symbolic port at the local host.

\( \text{getPortInfo} :: \text{String} \rightarrow \text{String} \rightarrow \text{IO} (\text{Int}, \text{Int}) \)
Gets the information about a symbolic port at some host.

\( \text{unregisterPort} :: \text{String} \rightarrow \text{IO} () \)
Unregisters a symbolic port at the local host.

\( \text{cpnsAlive} :: \text{Int} \rightarrow \text{String} \rightarrow \text{IO} \text{Bool} \)
Tests whether the CPNS demon at a host is alive.

\( \text{main} :: \text{IO} () \)
Main function for CPNS demon. Check arguments and execute command.
A.2.12 Library CSV

Library for reading/writing files in CSV format. Files in CSV (comma separated values) format can be imported and exported by most spreadsheet and database applications.

Exported functions:

writeCSVFile :: String → [[String]] → IO ()

  Writes a list of records (where each record is a list of strings) into a file in CSV format.

showCSV :: [[String]] → String

  Shows a list of records (where each record is a list of strings) as a string in CSV format.

readCSVFile :: String → IO [[String]]

  Reads a file in CSV format and returns the list of records (where each record is a list of strings).

readCSVFileWithDelims :: String → String → IO [[String]]

  Reads a file in CSV format and returns the list of records (where each record is a list of strings).

readCSV :: String → [[String]]

  Reads a string in CSV format and returns the list of records (where each record is a list of strings).

readCSVWithDelims :: String → String → [[String]]

  Reads a string in CSV format and returns the list of records (where each record is a list of strings).

A.2.13 Library Database

Library for accessing and storing data in databases. The contents of a database is represented in this library as dynamic predicates that are defined by facts than can change over time and can be persistently stored. All functions in this library distinguishes between queries that access the database and transactions that manipulates data in the database. Transactions have a monadic structure. Both queries and transactions can be executed as I/O actions. However, arbitrary I/O actions cannot be embedded in transactions.

A dynamic predicate \( p \) with arguments of type \( t_1, \ldots, t_n \) must be declared by:

\[
p :: t_1 \to \ldots \to t_n \to \text{Dynamic}
p = \text{dynamic}
\]

A dynamic predicate where all facts should be persistently stored in the directory \( \text{DIR} \) must be declared by:

\[
p :: t_1 \to \ldots \to t_n \to \text{Dynamic}
p = \text{persistent "file:DIR"}
\]
Exported types:

data Query

    Abstract datatype to represent database queries.

Exported constructors:

data TError

    The type of errors that might occur during a transaction.

Exported constructors:

    • TError :: TErrorKind → String → TError

data TErrorKind

    The various kinds of transaction errors.

Exported constructors:

    • KeyNotExistsError :: TErrorKind
    • NoRelationshipError :: TErrorKind
    • DuplicateKeyError :: TErrorKind
    • KeyRequiredError :: TErrorKind
    • UniqueError :: TErrorKind
    • MinError :: TErrorKind
    • MaxError :: TErrorKind
    • UserDefinedError :: TErrorKind
    • ExecutionError :: TErrorKind

data Transaction

    Abstract datatype for representing transactions.

Exported constructors:
Exported functions:

queryAll :: (a → Dynamic) → Query [a]

A database query that returns all answers to an abstraction on a dynamic expression.

queryOne :: (a → Dynamic) → Query (Maybe a)

A database query that returns a single answer to an abstraction on a dynamic expression. It returns Nothing if no answer exists.

queryOneWithDefault :: a → (a → Dynamic) → Query a

A database query that returns a single answer to an abstraction on a dynamic expression. It returns the first argument if no answer exists.

queryJustOne :: (a → Dynamic) → Query a

A database query that returns a single answer to an abstraction on a dynamic expression. It fails if no answer exists.

dynamicExists :: Dynamic → Query Bool

A database query that returns True if there exists the argument facts (without free variables!) and False, otherwise.

transformQ :: (a → b) → Query a → Query b

Transforms a database query from one result type to another according to a given mapping.

runQ :: Query a → IO a

Executes a database query on the current state of dynamic predicates. If other processes made changes to persistent predicates, these changes are read and made visible to the currently running program.

showTError :: TError → String

Transforms a transaction error into a string.

addDB :: Dynamic → Transaction ()

Adds new facts (without free variables!) about dynamic predicates. Conditional dynamics are added only if the condition holds.

deleteDB :: Dynamic → Transaction ()

Deletes facts (without free variables!) about dynamic predicates. Conditional dynamics are deleted only if the condition holds.

getDB :: Query a → Transaction a

Returns the result of a database query in a transaction.
returnT :: a → Transaction a

The empty transaction that directly returns its argument.

doneT :: Transaction ()

The empty transaction that returns nothing.

errorT :: TError → Transaction a

Abort a transaction with a specific transaction error.

failT :: String → Transaction a

Abort a transaction with a general error message.

(><>) :: Transaction a → (a → Transaction b) → Transaction b

Sequential composition of transactions.

(><>) :: Transaction a → Transaction b → Transaction b

Sequential composition of transactions.

sequenceT :: [Transaction a] → Transaction [a]

Executes a sequence of transactions and collects all results in a list.

sequenceT_ :: [Transaction a] → Transaction ()

Executes a sequence of transactions and ignores the results.

mapT :: (a → Transaction b) → [a] → Transaction [b]

Maps a transaction function on a list of elements. The results of all transactions are collected in a list.

mapT_ :: (a → Transaction b) → [a] → Transaction ()

Maps a transaction function on a list of elements. The results of all transactions are ignored.

runT :: Transaction a → IO (Either a TError)

Executes a possibly composed transaction on the current state of dynamic predicates as a single transaction.

Before the transaction is executed, the access to all persistent predicates is locked (i.e., no other process can perform a transaction in parallel). After the successful transaction, the access is unlocked so that the updates performed in this transaction become persistent and visible to other processes. Otherwise (i.e., in case of a failure or abort of the transaction), the changes of the transaction to persistent predicates are ignored and Nothing is returned.

In general, a transaction should terminate and all failures inside a transaction should be handled (except for an explicit failT that leads to an abort of the transaction). If a transaction is externally interrupted (e.g., by killing the process), some locks might never be removed. However, they can be explicitly removed by deleting the corresponding lock files reported at startup time.
runJustT :: Transaction a → IO a

Executes a possibly composed transaction on the current state of dynamic predicates as a single transaction. Similarly to runT but a run-time error is raised if the execution of the transaction fails.

runTNA :: Transaction a → IO (Either a TError)

Executes a possibly composed transaction as a Non-Atomic(!) sequence of its individual database updates. Thus, the argument is not executed as a single transaction in contrast to runT, i.e., no predicates are locked and individual updates are not undone in case of a transaction error. This operation could be applied to execute a composed transaction without the overhead caused by (the current implementation of) transactions if one is sure that locking is not necessary (e.g., if the transaction contains only database reads and transaction error raising).

A.2.14 Library Debug

Library for debugging operations.

Exported functions:

trace :: String → a → a

Prints the first argument as a side effect and behaves as identity on the second argument.

traceId :: String → String

Prints the first argument as a side effect and returns it afterwards.

traceShow :: a → b → b

Prints the first argument using show and returns the second argument afterwards.

traceShowId :: a → a

Prints the first argument using show and returns it afterwards.

traceIO :: String → IO ()

Output a trace message from the IO monad.

assert :: Bool → String → a → a

Assert a condition w.r.t. an error message. If the condition is not met it fails with the given error message, otherwise the third argument is returned.

assertIO :: Bool → String → IO ()

Assert a condition w.r.t. an error message from the IO monad. If the condition is not met it fails with the given error message.
A.2.15 Library Directory

Library for accessing the directory structure of the underlying operating system.

Exported functions:

\[
doesFileExist :: \text{String} \to \text{IO} \text{ Bool}
\]

Returns true if the argument is the name of an existing file.

\[
doesDirectoryExist :: \text{String} \to \text{IO} \text{ Bool}
\]

Returns true if the argument is the name of an existing directory.

\[
fileSize :: \text{String} \to \text{IO} \text{ Int}
\]

Returns the size of the file.

\[
getModificationTime :: \text{String} \to \text{IO} \text{ ClockTime}
\]

Returns the modification time of the file.

\[
getCurrentDirectory :: \text{IO} \text{ String}
\]

Returns the current working directory.

\[
setCurrentDirectory :: \text{String} \to \text{IO} ()
\]

Sets the current working directory.

\[
getDirectoryContents :: \text{String} \to \text{IO} \text{ [String]}
\]

Returns the list of all entries in a directory.

\[
createDirectory :: \text{String} \to \text{IO} ()
\]

Creates a new directory with the given name.

\[
createDirectoryIfMissing :: \text{Bool} \to \text{String} \to \text{IO} ()
\]

Creates a new directory with the given name if it does not already exist. If the first parameter is True it will also create all missing parent directories.

\[
removeDirectory :: \text{String} \to \text{IO} ()
\]

Deletes a directory from the file system.

\[
renameDirectory :: \text{String} \to \text{String} \to \text{IO} ()
\]

Renames a directory.

\[
getHomeDirectory :: \text{IO} \text{ String}
\]

Returns the home directory of the current user.
getTemporaryDirectory :: IO String

Returns the temporary directory of the operating system.

getAbsolutePath :: String → IO String

Convert a path name into an absolute one. For instance, a leading ~ is replaced by the current home directory.

removeFile :: String → IO ()

Deletes a file from the file system.

renameFile :: String → String → IO ()

 Renames a file.

copyFile :: String → String → IO ()

 Copy the contents from one file to another file

A.2.16 Library Distribution

This module contains functions to obtain information concerning the current distribution of the Curry implementation. Most of the information is based on the external constants curryCompiler....

Exported types:

data FrontendTarget

Data type for representing the different target files that can be produced by the frontend of the Curry compiler.

Exported constructors:

• FCY :: FrontendTarget
  FCY
  – FlatCurry file ending with .fcy

• FINT :: FrontendTarget
  FINT
  – FlatCurry interface file ending with .fint

• ACY :: FrontendTarget
  ACY
  – AbstractCurry file ending with .acy
• **UACY** :: FrontendTarget
  
  **UACY**
  
  – Untyped (without type checking) AbstractCurry file ending with .uacy

• **HTML** :: FrontendTarget
  
  **HTML**
  
  – colored HTML representation of source program

• **CY** :: FrontendTarget
  
  **CY**
  
  – source representation employed by the frontend

```haskell
data FrontendParams

  Abstract data type for representing parameters supported by the front end of the Curry compiler.

  *Exported constructors:*

  **Exported functions:**

  **curryCompiler** :: String

  The name of the Curry compiler (e.g., “pakcs” or “kics2”).

  **curryCompilerMajorVersion** :: Int

  The major version number of the Curry compiler.

  **curryCompilerMinorVersion** :: Int

  The minor version number of the Curry compiler.

  **curryRuntime** :: String

  The name of the run-time environment (e.g., “sicstus”, “swi”, or “ghc”)

  **curryRuntimeMajorVersion** :: Int

  The major version number of the Curry run-time environment.

  **curryRuntimeMinorVersion** :: Int

  The minor version number of the Curry run-time environment.

  **installDir** :: String

  Path of the main installation directory of the Curry compiler.

  **rcFileName** :: IO String
```
The name of the file specifying configuration parameters of the current distribution. This file must have the usual format of property files (see description in module PropertyFile).

\[
rcFileContents :: IO [(String,String)]
\]

Returns the current configuration parameters of the distribution. This action yields the list of pairs (var,val).

\[
getRcVar :: String \rightarrow IO (Maybe String)
\]

Look up a specific configuration variable as specified by user in his rc file. Uppercase/lowercase is ignored for the variable names.

\[
getRcVars :: [String] \rightarrow IO [Maybe String]
\]

Look up configuration variables as specified by user in his rc file. Uppercase/lowercase is ignored for the variable names.

\[
splitModuleFileName :: String \rightarrow String \rightarrow (String,String)
\]

Split the FilePath of a module into the directory prefix and the FilePath corresponding to the module name. For instance, the call \texttt{splitModuleFileName "Data.Set" "lib/Data/Set.curry"} evaluates to ("lib", "Data/Set.curry"). This can be useful to compute output directories while retaining the hierarchical module structure.

\[
splitModuleIdentifiers :: String \rightarrow [String]
\]

Split up the components of a module identifier. For instance, \texttt{splitModuleIdentifiers "Data.Set"} evaluates to ["Data", "Set"].

\[
joinModuleIdentifiers :: [String] \rightarrow String
\]

Join the components of a module identifier. For instance, \texttt{joinModuleIdentifiers ["Data", "Set"]} evaluates to "Data.Set".

\[
stripCurrySuffix :: String \rightarrow String
\]

Strips the suffix ".curry" or ".lcurry" from a file name.

\[
modNameToPath :: String \rightarrow String
\]

Transforms a hierarchical module name into a path name, i.e., replace the dots in the name by directory separator chars.

\[
currySubdir :: String
\]

Name of the sub directory where auxiliary files (.fint, .fcy, etc) are stored.

\[
inCurrySubdir :: String \rightarrow String
\]

Transforms a path to a module name into a file name by adding the \texttt{currySubDir} to the path and transforming a hierarchical module name into a path. For instance, \texttt{inCurrySubdir "mylib/Data.Char"} evaluates to "mylib/.curry/Data/Char".
inCurrySubdirModule :: String → String → String

Transforms a file name by adding the currySubDir to the file name. This version respects hierarchical module names.

addCurrySubdir :: String → String

Transforms a directory name into the name of the corresponding sub directory containing auxiliary files.

lookupFileInLoadPath :: String → IO (Maybe String)

Adds a directory name to a file by looking up the current load path. An error message is delivered if there is no such file.

findFileInLoadPath :: String → IO String

Adds a directory name to a file by looking up the current load path. An error message is delivered if there is no such file.

readFirstFileInLoadPath :: String → IO String

Returns the contents of the file found first in the current load path. An error message is delivered if there is no such file.

getAddress :: IO [String]

Returns the current path (list of directory names) that is used for loading modules.

getAddressForFile :: String → IO [String]

Returns the current path (list of directory names) that is used for loading modules w.r.t. a given main module file. The directory prefix of the module file (or "." if there is no such prefix) is the first element of the load path and the remaining elements are determined by the environment variable CURRYRPATH and the entry "libraries" of the system’s rc file.

getAddressForModule :: String → IO [String]

Returns the current path (list of directory names) that is used for loading modules w.r.t. a given module path. The directory prefix of the module path (or "." if there is no such prefix) is the first element of the load path and the remaining elements are determined by the environment variable CURRYRPATH and the entry "libraries" of the system’s rc file.

lookupModuleSourceInLoadPath :: String → IO (Maybe (String,String))

Returns a directory name and the actual source file name for a module by looking up the module source in the current load path. If the module is hierarchical, the directory is the top directory of the hierarchy. Returns Nothing if there is no corresponding source file.
defaultParams :: FrontendParams

The default parameters of the front end.

rcParams :: IO FrontendParams

The default parameters of the front end as configured by the compiler specific resource configuration file.

setQuiet :: Bool \rightarrow FrontendParams \rightarrow FrontendParams

Set quiet mode of the front end.

setExtended :: Bool \rightarrow FrontendParams \rightarrow FrontendParams

Set extended mode of the front end.

setOverlapWarn :: Bool \rightarrow FrontendParams \rightarrow FrontendParams

Set overlap warn mode of the front end.

setFullPath :: [String] \rightarrow FrontendParams \rightarrow FrontendParams

Set the full path of the front end. If this parameter is set, the front end searches all modules in this path (instead of using the default path).

setHtmlDir :: String \rightarrow FrontendParams \rightarrow FrontendParams

Set the htmldir parameter of the front end. Relevant for HTML generation.

setLogfile :: String \rightarrow FrontendParams \rightarrow FrontendParams

Set the logfile parameter of the front end. If this parameter is set, all messages produced by the front end are stored in this file.

setSpecials :: String \rightarrow FrontendParams \rightarrow FrontendParams

Set additional specials parameters of the front end. These parameters are specific for the current front end and should be used with care, since their form might change in the future.

quiet :: FrontendParams \rightarrow Bool

Returns the value of the "quiet" parameter.

extended :: FrontendParams \rightarrow Bool

Returns the value of the "extended" parameter.

overlapWarn :: FrontendParams \rightarrow Bool

Returns the value of the "overlapWarn" parameter.

fullPath :: FrontendParams \rightarrow Maybe [String]

76
Returns the full path parameter of the front end.

\texttt{htmldir :: FrontendParams \rightarrow Maybe String}

Returns the htmldir parameter of the front end.

\texttt{logfile :: FrontendParams \rightarrow Maybe String}

Returns the logfile parameter of the front end.

\texttt{specials :: FrontendParams \rightarrow String}

Returns the special parameters of the front end.

\texttt{callFrontend :: FrontendTarget \rightarrow String \rightarrow IO ()}

In order to make sure that compiler generated files (like .fcy, .fint, .acy) are up to date, one can call the front end of the Curry compiler with this action. If the front end returns with an error, an exception is raised.

\texttt{callFrontendWithParams :: FrontendTarget \rightarrow FrontendParams \rightarrow String \rightarrow IO ()}

In order to make sure that compiler generated files (like .fcy, .fint, .acy) are up to date, one can call the front end of the Curry compiler with this action where various parameters can be set. If the front end returns with an error, an exception is raised.

A.2.17 Library Dynamic

Library for dynamic predicates. \footnote{http://www.informatik.uni-kiel.de/~mh/papers/JFLP04} This paper contains a description of the basic ideas behind this library.

Currently, it is still experimental so that its interface might be slightly changed in the future.

A dynamic predicate \( p \) with arguments of type \( t_1, \ldots, t_n \) must be declared by:

\( p :: t_1 \rightarrow \ldots \rightarrow t_n \rightarrow \text{Dynamic} \)

\( p = \text{dynamic} \)

A dynamic predicate where all facts should be persistently stored in the directory \( \text{DIR} \) must be declared by:

\( p :: t_1 \rightarrow \ldots \rightarrow t_n \rightarrow \text{Dynamic} \)

\( p = \text{persistent "file:DIR"} \)

Remark: This library has been revised to the library \texttt{Database}. Thus, it might not be further supported in the future.

Exported types:

\texttt{data Dynamic}

The general type of dynamic predicates.

\textit{Exported constructors:}

\footnote{http://www.informatik.uni-kiel.de/~mh/papers/JFLP04}
Exported functions:

dynamic :: a

dynamic is only used for the declaration of a dynamic predicate and should not be used elsewhere.

persistent :: String → a

persistent is only used for the declaration of a persistent dynamic predicate and should not be used elsewhere.

(<>): Dynamic → Dynamic → Dynamic

Combine two dynamics.

(|>): Dynamic → Bool → Dynamic

Restrict a dynamic with a condition.

(|&>): Dynamic → Success → Dynamic

Restrict a dynamic with a constraint.

assert :: Dynamic → IO ()

Asserts new facts (without free variables!) about dynamic predicates. Conditional dynamics are asserted only if the condition holds.

retract :: Dynamic → IO Bool

Deletes facts (without free variables!) about dynamic predicates. Conditional dynamics are retracted only if the condition holds. Returns True if all facts to be retracted exist, otherwise False is returned.

getAddress :: IO (Dynamic → Success)

Returns the knowledge at a particular point of time about dynamic predicates. If other processes made changes to persistent predicates, these changes are read and made visible to the currently running program.

getAddressSolutions :: (a → Dynamic) → IO [a]

Returns all answers to an abstraction on a dynamic expression. If other processes made changes to persistent predicates, these changes are read and made visible to the currently running program.

getAddressSolution :: (a → Dynamic) → IO (Maybe a)

Returns an answer to an abstraction on a dynamic expression. Returns Nothing if no answer exists. If other processes made changes to persistent predicates, these changes are read and made visible to the currently running program.
isKnown :: Dynamic → IO Bool

    Returns True if there exists the argument facts (without free variables!) and False, otherwise.

transaction :: IO a → IO (Maybe a)

    Perform an action (usually containing updates of various dynamic predicates) as a single transaction. This is the preferred way to execute any changes to persistent dynamic predicates if there might be more than one process that may modify the definition of such predicates in parallel.

    Before the transaction is executed, the access to all persistent predicates is locked (i.e., no other process can perform a transaction in parallel). After the successful transaction, the access is unlocked so that the updates performed in this transaction become persistent and visible to other processes. Otherwise (i.e., in case of a failure or abort of the transaction), the changes of the transaction to persistent predicates are ignored and Nothing is returned.

    In general, a transaction should terminate and all failures inside a transaction should be handled (except for abortTransaction). If a transaction is externally interrupted (e.g., by killing the process), some locks might never be removed. However, they can be explicitly removed by deleting the corresponding lock files reported at startup time. Nested transactions are not supported and lead to a failure.

transactionWithErrorCatch :: IO a → IO (Either a IOError)

    Perform an action (usually containing updates of various dynamic predicates) as a single transaction. This is similar to transaction but an execution error is caught and returned instead of printing it.

abortTransaction :: IO a

    Aborts the current transaction. If a transaction is aborted, the remaining actions of the transaction are not executed and all changes to persistent dynamic predicates made in this transaction are ignored.

    abortTransaction should only be used in a transaction. Although the execution of abortTransaction always fails (basically, it writes an abort record in log files, unlock them and then fails), the failure is handled inside transaction.

A.2.18 Library Either

Library with some useful operations for the Either data type.
Exported functions:

\[\text{lefts :: [Either } a \; b] \rightarrow [a]\]

Extracts from a list of \text{Either} all the \text{Left} elements in order.

\[\text{rights :: [Either } a \; b] \rightarrow [b]\]

Extracts from a list of \text{Either} all the \text{Right} elements in order.

\[\text{isLeft :: Either } a \; b \rightarrow \text{Bool}\]

Return \text{True} if the given value is a \text{Left}-value, \text{False} otherwise.

\[\text{isRight :: Either } a \; b \rightarrow \text{Bool}\]

Return \text{True} if the given value is a \text{Right}-value, \text{False} otherwise.

\[\text{partitionEithers :: [Either } a \; b] \rightarrow ([a],[b])\]

Partitions a list of \text{Either} into two lists. All the \text{Left} elements are extracted, in order, to the first component of the output. Similarly the \text{Right} elements are extracted to the second component of the output.

\section*{A.2.19 Library FileGoodies}

A collection of useful operations when dealing with files.

Exported functions:

\[\text{separatorChar :: Char}\]

The character for separating hierarchies in file names. On UNIX systems the value is \\
/

\[\text{pathSeparatorChar :: Char}\]

The character for separating names in path expressions. On UNIX systems the value is \\
:

\[\text{suffixSeparatorChar :: Char}\]

The character for separating suffixes in file names. On UNIX systems the value is \\
.

\[\text{isAbsolute :: String } \rightarrow \text{Bool}\]

Is the argument an absolute name?

\[\text{dirName :: String } \rightarrow \text{String}\]

Extracts the directory prefix of a given (Unix) file name. Returns "." if there is no prefix.

\[\text{baseName :: String } \rightarrow \text{String}\]
Extracts the base name without directory prefix of a given (Unix) file name.

\[
\text{splitDirectoryBaseName :: String} \rightarrow (\text{String}, \text{String})
\]

Splits a (Unix) file name into the directory prefix and the base name. The directory prefix is "." if there is no real prefix in the name.

\[
\text{stripSuffix :: String} \rightarrow \text{String}
\]

Strips a suffix (the last suffix starting with a dot) from a file name.

\[
\text{fileSuffix :: String} \rightarrow \text{String}
\]

Yields the suffix (the last suffix starting with a dot) from given file name.

\[
\text{splitBaseName :: String} \rightarrow (\text{String}, \text{String})
\]

Splits a file name into prefix and suffix (the last suffix starting with a dot and the rest).

\[
\text{splitPath :: String} \rightarrow [\text{String}]
\]

Splits a path string into list of directory names.

\[
\text{lookupFileInPath :: String} \rightarrow [\text{String}] \rightarrow [\text{String}] \rightarrow \text{IO} \ (\text{Maybe String})
\]

Looks up the first file with a possible suffix in a list of directories. Returns Nothing if such a file does not exist.

\[
\text{getFileInPath :: String} \rightarrow [\text{String}] \rightarrow [\text{String}] \rightarrow \text{IO} \ \text{String}
\]

Gets the first file with a possible suffix in a list of directories. An error message is delivered if there is no such file.

**A.2.20 Library FilePath**

This library is a direct port of the Haskell library System.FilePath of Neil Mitchell.

**Exported types:**

\[
\text{type FilePath = String}
\]

**Exported functions:**

\[
\text{pathSeparator :: Char}
\]

\[
\text{pathSeparators :: String}
\]

\[
\text{isPathSeparator :: Char} \rightarrow \text{Bool}
\]
searchPathSeparator :: Char

isSearchPathSeparator :: Char → Bool

extSeparator :: Char

isExtSeparator :: Char → Bool

splitSearchPath :: String → [String]

getSearchPath :: IO [String]

splitExtension :: String → (String,String)

takeExtension :: String → String

replaceExtension :: String → String → String

(<.>) :: String → String → String

dropExtension :: String → String

addExtension :: String → String → String

hasExtension :: String → Bool

splitExtensions :: String → (String,String)
dropExtensions :: String → String

takeExtensions :: String → String

splitDrive :: String → (String,String)

joinDrive :: String → String → String

takeDrive :: String → String

dropDrive :: String → String

hasDrive :: String → Bool

isDrive :: String → Bool

splitFileName :: String → (String,String)

replaceFileName :: String → String → String

dropFileName :: String → String

takeFileName :: String → String

takeBaseName :: String → String

replaceBaseName :: String → String → String
hasTrailingPathSeparator :: String → Bool

addTrailingPathSeparator :: String → String

dropTrailingPathSeparator :: String → String

takeDirectory :: String → String

replaceDirectory :: String → String → String

combine :: String → String → String

(</>): String → String → String

splitPath :: String → [String]

splitDirectories :: String → [String]

joinPath :: [String] → String

equalFilePath :: String → String → Bool

makeRelative :: String → String → String

normalise :: String → String

isValid :: String → Bool
makeValid :: String → String

isRelative :: String → Bool

isAbsolute :: String → Bool

A.2.21 Library Float
A collection of operations on floating point numbers.

Exported functions:
pi :: Float
   The number pi.
(+.) :: Float → Float → Float
   Addition on floats.
(-.) :: Float → Float → Float
   Subtraction on floats.
(*.) :: Float → Float → Float
   Multiplication on floats.
(/.) :: Float → Float → Float
   Division on floats.
(^.) :: Float → Int → Float
   The value of a ^ . b is a raised to the power of b. Executes in O(log b) steps.
i2f :: Int → Float
   Conversion function from integers to floats.
truncate :: Float → Int
   Conversion function from floats to integers. The result is the closest integer between the argument and 0.
round :: Float → Int
Conversion function from floats to integers. The result is the nearest integer to the argument. If the argument is equidistant between two integers, it is rounded to the closest even integer value.

\[
\text{recip} :: \text{Float} \rightarrow \text{Float}
\]
Reciprocal

\[
\text{sqrt} :: \text{Float} \rightarrow \text{Float}
\]
Square root.

\[
\text{log} :: \text{Float} \rightarrow \text{Float}
\]
Natural logarithm.

\[
\text{logBase} :: \text{Float} \rightarrow \text{Float} \rightarrow \text{Float}
\]
Logarithm to arbitrary Base.

\[
\text{exp} :: \text{Float} \rightarrow \text{Float}
\]
Natural exponent.

\[
\text{sin} :: \text{Float} \rightarrow \text{Float}
\]
Sine.

\[
\text{cos} :: \text{Float} \rightarrow \text{Float}
\]
Cosine.

\[
\text{tan} :: \text{Float} \rightarrow \text{Float}
\]
Tangent.

\[
\text{asin} :: \text{Float} \rightarrow \text{Float}
\]
Arc sine.

\[
\text{acos} :: \text{Float} \rightarrow \text{Float}
\]

\[
\text{atan} :: \text{Float} \rightarrow \text{Float}
\]
Arc tangent.

\[
\text{sinh} :: \text{Float} \rightarrow \text{Float}
\]
Hyperbolic sine.

\[
\text{cosh} :: \text{Float} \rightarrow \text{Float}
\]
tanh :: Float → Float

Hyperbolic tangent.

asinh :: Float → Float

Hyperbolic Arc sine.

acosh :: Float → Float

atanh :: Float → Float

Hyperbolic Arc tangent.

A.2.22 Library Function

This module provides some utility functions for function application.

Exported functions:

fix :: (a → a) → a

fix f is the least fixed point of the function f, i.e. the least defined x such that f x = x.

on :: (a → a → b) → (c → a) → c → c → b

(*') 'on' f = \x y → f x * f y. Typical usage: sortBy (compare 'on' fst).

first :: (a → b) → (a,c) → (b,c)

Apply a function to the first component of a tuple.

second :: (a → b) → (c,a) → (c,b)

Apply a function to the second component of a tuple.

(***)) :: (a → b) → (c → d) → (a,c) → (b,d)

Apply two functions to the two components of a tuple.

(kkk) :: (a → b) → (a → c) → a → (b,c)

Apply two functions to a value and returns a tuple of the results.

both :: (a → b) → (a,a) → (b,b)

Apply a function to both components of a tuple.
A.2.23  Library FunctionInversion

This module provides some utility functions for inverting functions.

Exported functions:

invf1 :: (a -> b) -> b -> a

Inverts a unary function.

invf2 :: (a -> b -> c) -> c -> (a,b)

Inverts a binary function.

invf3 :: (a -> b -> c -> d) -> d -> (a,b,c)

Inverts a ternary function.

invf4 :: (a -> b -> c -> d -> e) -> e -> (a,b,c,d)

Inverts a function of arity 4.

invf5 :: (a -> b -> c -> d -> e -> f) -> f -> (a,b,c,d,e)

Inverts a function of arity 5.

A.2.24  Library GetOpt

This Module is a modified version of the Module System.Console.GetOpt by Sven Panne from the ghc-base package it has been adapted for Curry by Bjoern Peemoeller

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WARE, EVEN IF ADVISED OF THE POSSIBILITY OF SUCH DAMAGE. ————————

Exported types:

data ArgOrder

  Exported constructors:

  • RequireOrder :: ArgOrder a
  • Permute :: ArgOrder a
  • ReturnInOrder :: (String → a) → ArgOrder a

data OptDescr

  Exported constructors:

  • Option :: String → [String] → (ArgDescr a) → String → OptDescr a

data ArgDescr

  Exported constructors:

  • NoArg :: a → ArgDescr a
  • ReqArg :: (String → a) → String → ArgDescr a
  • OptArg :: (Maybe String → a) → String → ArgDescr a
Exported functions:

usageInfo :: String → [OptDescr a] → String

getOpt :: ArgOrder a → [OptDescr a] → [String] → ([a],[String],[String])

getOpt' :: ArgOrder a → [OptDescr a] → [String] → ([a],[String],[String],[String])

A.2.25 Library Global

Library for handling global entities. A global entity has a name declared in the program. Its value can be accessed and modified by IO actions. Furthermore, global entities can be declared as persistent so that their values are stored across different program executions. Currently, it is still experimental so that its interface might be slightly changed in the future.

A global entity \( g \) with an initial value \( v \) of type \( t \) must be declared by:

\[
\begin{align*}
g & :: \text{Global } t \\
g & = \text{global } v \text{ spec}
\end{align*}
\]

Here, the type \( t \) must not contain type variables and \( \text{spec} \) specifies the storage mechanism for the global entity (see type \( \text{GlobalSpec} \)).

Exported types:

data Global

The type of a global entity.

\textit{Exported constructors:}

data GlobalSpec

The storage mechanism for the global entity.

\textit{Exported constructors:}

- \textbf{Temporary} :: GlobalSpec
  
  \textit{Temporary}

  - the global value exists only during a single execution of a program

- \textbf{Persistent} :: String → GlobalSpec

  \textit{Persistent } f

  - the global value is stored persistently in file \( f \) (which is created and initialized if it does not exists)
Exported functions:

global :: a → GlobalSpec → Global a

  global is only used for the declaration of a global value and should not be used elsewhere. In the future, it might become a keyword.

readGlobal :: Global a → IO a

  Reads the current value of a global.

writeGlobal :: Global a → a → IO ()

  Updates the value of a global. The value is evaluated to a ground constructor term before it is updated.

A.2.26 Library GlobalVariable

Library for handling global variables. A global variable has a name declared in the program. Its value (a data term possibly containing free variables) can be accessed and modified by IO actions. In contrast to global entities (as defined in the library Global), global variables can contain logic variables shared with computations running in the same computation space. As a consequence, global variables cannot be persistent, their values are not kept across different program executions. Currently, it is still experimental so that its interface might be slightly changed in the future.

A global variable $g$ with an initial value $v$ of type $t$ must be declared by:

g :: GVar t

  g = gvar v

Here, the type $t$ must not contain type variables. $v$ is the initial value for every program run.

Note: the implementation in PAKCS is based on threading a state through the execution. Thus, it might be the case that some updates of global variables are lost if fancy features like unsafe operations or debugging support are used.

Exported types:

data GVar

  The general type of global variables.

Exported constructors:

Exported functions:

gvar :: a → GVar a

  gvar is only used for the declaration of a global variable and should not be used elsewhere. In the future, it might become a keyword.

readGVar :: GVar a → IO a

  Reads the current value of a global variable.
writeGVar :: GVar a → a → IO ()

Updates the value of a global variable. The associated term is evaluated to a data term and might contain free variables.

A.2.27 Library GUI

Library for GUI programming in Curry (based on Tcl/Tk). This paper contains a description of the basic ideas behind this library.

Exported types:

data GuiPort

The port to a GUI is just the stream connection to a GUI where Tcl/Tk communication is done.

Exported constructors:

data Widget

The type of possible widgets in a GUI.

Exported constructors:

• PlainButton :: [ConfItem] → Widget
  PlainButton
  – a button in a GUI whose event handler is activated if the user presses the button

• Canvas :: [ConfItem] → Widget
  Canvas
  – a canvas to draw pictures containing CanvasItems

• CheckButton :: [ConfItem] → Widget
  CheckButton
  – a check button: it has value "0" if it is unchecked and value "1" if it is checked

• Entry :: [ConfItem] → Widget
  Entry
  – an entry widget for entering single lines

• Label :: [ConfItem] → Widget
  Label
  – a label for showing a text
• **ListBox** :: [ConfItem] → Widget
  
  ListBox
  
  – a widget containing a list of items for selection

• **Message** :: [ConfItem] → Widget
  
  Message
  
  – a message for showing simple string values

• **MenuButton** :: [ConfItem] → Widget
  
  MenuButton
  
  – a button with a pull-down menu

• **Scale** :: Int → Int → [ConfItem] → Widget
  
  Scale
  
  – a scale widget to input values by a slider

• **ScrollH** :: WidgetRef → [ConfItem] → Widget
  
  ScrollH
  
  – a horizontal scroll bar

• **ScrollV** :: WidgetRef → [ConfItem] → Widget
  
  ScrollV
  
  – a vertical scroll bar

• **TextEdit** :: [ConfItem] → Widget
  
  TextEdit
  
  – a text editor widget to show and manipulate larger text paragraphs

• **Row** :: [ConfCollection] → [Widget] → Widget
  
  Row
  
  – a horizontal alignment of widgets

• **Col** :: [ConfCollection] → [Widget] → Widget
  
  Col
  
  – a vertical alignment of widgets

• **Matrix** :: [ConfCollection] → [[Widget]] → Widget
  
  Matrix
  
  – a 2-dimensional (matrix) alignment of widgets
data ConfItem

The data type for possible configurations of a widget.

*Exported constructors:*

- **Active :: Bool → ConfItem**
  Active
  - define the active state for buttons, entries, etc.

- **Anchor :: String → ConfItem**
  Anchor
  - alignment of information inside a widget where the argument must be: n, ne, e, se, s, sw, w, nw, or center

- **Background :: String → ConfItem**
  Background
  - the background color

- **Foreground :: String → ConfItem**
  Foreground
  - the foreground color

- **Handler :: Event → (GuiPort → IO [ReconfigureItem]) → ConfItem**
  Handler
  - an event handler associated to a widget. The event handler returns a list of widget ref/configuration pairs that are applied after the handler in order to configure GUI widgets

- **Height :: Int → ConfItem**
  Height
  - the height of a widget (chars for text, pixels for graphics)

- **CheckInit :: String → ConfItem**
  CheckInit
  - initial value for checkbuttons

- **CanvasItems :: [CanvasItem] → ConfItem**
  CanvasItems
  - list of items contained in a canvas
data ReconfigureItem

Data type for describing configurations that are applied to a widget or GUI by some event handler.
Exported constructors:

- WidgetConf :: WidgetRef → ConfItem → ReconfigureItem
  WidgetConf wref conf
  -- reconfigure the widget referred by wref with configuration item conf

- StreamHandler :: Handle → (Handle → GuiPort → IO [ReconfigureItem]) → ReconfigureItem
  StreamHandler hdl handler
  -- add a new handler to the GUI that processes inputs on an input stream referred by hdl

- RemoveStreamHandler :: Handle → ReconfigureItem
  RemoveStreamHandler hdl
  -- remove a handler for an input stream referred by hdl from the GUI (usually used to remove handlers for closed streams)

data Event

  The data type of possible events on which handlers can react. This list is still incomplete and might be extended or restructured in future releases of this library.

Exported constructors:

- DefaultEvent :: Event
  DefaultEvent
  -- the default event of the widget

- MouseButton1 :: Event
  MouseButton1
  -- left mouse button pressed

- MouseButton2 :: Event
  MouseButton2
  -- middle mouse button pressed

- MouseButton3 :: Event
  MouseButton3
  -- right mouse button pressed

- KeyPress :: Event
  KeyPress
any key is pressed

• Return :: Event
  Return
  – return key is pressed

data ConfCollection

  The data type for possible configurations of widget collections (e.g., columns, rows).

  Exported constructors:

  • CenterAlign :: ConfCollection
    CenterAlign
    – centered alignment
  
  • LeftAlign :: ConfCollection
    LeftAlign
    – left alignment
  
  • RightAlign :: ConfCollection
    RightAlign
    – right alignment
  
  • TopAlign :: ConfCollection
    TopAlign
    – top alignment
  
  • BottomAlign :: ConfCollection
    BottomAlign
    – bottom alignment

data MenuItem

  The data type for specifying items in a menu.

  Exported constructors:

  • MButton :: (GuiPort → IO [ReconfigureItem]) → String → MenuItem
    MButton
    – a button with an associated command and a label string
• MSeparator :: MenuItem
MSeparator
  – a separator between menu entries

• MMenuButton :: String → [MenuItem] → MenuItem
MMenuButton
  – a submenu with a label string

data CanvasItem

  The data type of items in a canvas. The last argument are further options in Tcl/Tk
  (for testing).

  Exported constructors:

  • CLine :: [(Int,Int)] → String → CanvasItem
  • CPolygon :: [(Int,Int)] → String → CanvasItem
  • CRectangle :: (Int,Int) → (Int,Int) → String → CanvasItem
  • COval :: (Int,Int) → (Int,Int) → String → CanvasItem
  • CText :: (Int,Int) → String → String → CanvasItem

data WidgetRef

  The (hidden) data type of references to a widget in a GUI window. Note that the
  constructor WRefLabel will not be exported so that values can only be created inside
  this module.

  Exported constructors:

data Style

  The data type of possible text styles.

  Exported constructors:

  • Bold :: Style
    Bold
    – text in bold font
  • Italic :: Style
    Italic
    – text in italic font
• Underline :: Style
  Underline
  – underline text
• Fg :: Color → Style
  Fg
  – foreground color, i.e., color of the text font
• Bg :: Color → Style
  Bg
  – background color of the text

data Color
  The data type of possible colors.

  Exported constructors:
  • Black :: Color
  • Blue :: Color
  • Brown :: Color
  • Cyan :: Color
  • Gold :: Color
  • Gray :: Color
  • Green :: Color
  • Magenta :: Color
  • Navy :: Color
  • Orange :: Color
  • Pink :: Color
  • Purple :: Color
  • Red :: Color
  • Tomato :: Color
  • Turquoise :: Color
  • Violet :: Color
  • White :: Color
  • Yellow :: Color
Exported functions:

- **row**: \[[\text{Widget}]\] → \text{Widget}
  - Horizontal alignment of widgets.

- **col**: \[[\text{Widget}]\] → \text{Widget}
  - Vertical alignment of widgets.

- **matrix**: \[[[\text{Widget}]\]] → \text{Widget}
  - Matrix alignment of widgets.

- **debugTcl**: \text{Widget} → \text{IO ()}
  - Prints the generated Tcl commands of a main widget (useful for debugging).

- **runPassiveGUI**: String → \text{Widget} → \text{IO GuiPort}
  - IO action to show a Widget in a new GUI window in passive mode, i.e., ignore all GUI events.

- **runGUI**: String → \text{Widget} → \text{IO ()}
  - IO action to run a Widget in a new window.

- **runGUIwithParams**: String → String → \text{Widget} → \text{IO ()}
  - IO action to run a Widget in a new window.

- **runInitGUI**: String → \text{Widget} → (GuiPort → \text{IO [ReconfigureItem]}) → \text{IO ()}
  - IO action to run a Widget in a new window. The GUI events are processed after executing an initial action on the GUI.

- **runInitGUIwithParams**: String → String → \text{Widget} → (GuiPort → \text{IO [ReconfigureItem]}) → \text{IO ()}
  - IO action to run a Widget in a new window. The GUI events are processed after executing an initial action on the GUI.

- **runControlledGUI**: String → (\text{Widget,} String → GuiPort → \text{IO ()}) → \text{Handle} → \text{IO ()}
  - Runs a Widget in a new GUI window and process GUI events. In addition, an event handler is provided that process messages received from an external stream identified by a handle (third argument). This operation is useful to run a GUI that should react on user events as well as messages written to the given handle.

- **runConfigControlledGUI**: String → (\text{Widget,} String → GuiPort → \text{IO [ReconfigureItem]}) → \text{Handle} → \text{IO ()}
Runs a Widget in a new GUI window and process GUI events. In addition, an event handler is provided that process messages received from an external stream identified by a handle (third argument). This operation is useful to run a GUI that should react on user events as well as messages written to the given handle.

\[
\text{runInitControlledGUI :: String } \rightarrow \ (\text{Widget, String } \rightarrow \ \text{GuiPort } \rightarrow \ \text{IO } (\)) \rightarrow \ (\text{GuiPort } \rightarrow \ \text{IO } \) [\text{ReconfigureItem}] \rightarrow \ \text{Handle } \rightarrow \ \text{IO } (\)
\]

Runs a Widget in a new GUI window and process GUI events after executing an initial action on the GUI window. In addition, an event handler is provided that process messages received from an external message stream. This operation is useful to run a GUI that should react on user events as well as messages written to the given handle.

\[
\text{runHandlesControlledGUI :: String } \rightarrow \ (\text{Widget, [Handle } \rightarrow \ \text{GuiPort } \rightarrow \ \text{IO } \) [\text{ReconfigureItem}]]) \rightarrow \ [\text{Handle}] \rightarrow \ \text{IO } (\)
\]

Runs a Widget in a new GUI window and process GUI events. In addition, a list of event handlers is provided that process inputs received from a corresponding list of handles to input streams. Thus, if the i-th handle has some data available, the i-th event handler is executed with the i-th handle as a parameter. This operation is useful to run a GUI that should react on inputs provided by other processes, e.g., via sockets.

\[
\text{runInitHandlesControlledGUI :: String } \rightarrow \ (\text{Widget, [Handle } \rightarrow \ \text{GuiPort } \rightarrow \ \text{IO } \) [\text{ReconfigureItem}]]) \rightarrow \ (\text{GuiPort } \rightarrow \ \text{IO } \) [\text{ReconfigureItem}] \rightarrow \ [\text{Handle}] \rightarrow \ \text{IO } (\)
\]

Runs a Widget in a new GUI window and process GUI events after executing an initial action on the GUI window. In addition, a list of event handlers is provided that process inputs received from a corresponding list of handles to input streams. Thus, if the i-th handle has some data available, the i-th event handler is executed with the i-th handle as a parameter. This operation is useful to run a GUI that should react on inputs provided by other processes, e.g., via sockets.

\[
\text{getConfig :: WidgetRef } \rightarrow \ \text{ConfItem } \rightarrow \ \text{GuiPort } \rightarrow \ \text{IO } (\)
\]

Changes the current configuration of a widget (deprecated operation, only included for backward compatibility). Warning: does not work for Command options!

\[
\text{exitGUI :: GuiPort } \rightarrow \ \text{IO } (\)
\]

An event handler for terminating the GUI.

\[
\text{getValue :: WidgetRef } \rightarrow \ \text{GuiPort } \rightarrow \ \text{IO String}
\]

Gets the (String) value of a variable in a GUI.

\[
\text{setValue :: WidgetRef } \rightarrow \ \text{String } \rightarrow \ \text{GuiPort } \rightarrow \ \text{IO } (\)
\]

Sets the (String) value of a variable in a GUI.

\[
\text{updateValue :: (String } \rightarrow \ \text{String}) \rightarrow \ \text{WidgetRef } \rightarrow \ \text{GuiPort } \rightarrow \ \text{IO } (\)
\]
Updates the (String) value of a variable w.r.t. to an update function.

\[
\text{appendValue} :: \text{WidgetRef} \rightarrow \text{String} \rightarrow \text{GuiPort} \rightarrow \text{IO} ()
\]

Appends a String value to the contents of a TextEdit widget and adjust the view to the end of the TextEdit widget.

\[
\text{appendStyledValue} :: \text{WidgetRef} \rightarrow \text{String} \rightarrow \text{[Style]} \rightarrow \text{GuiPort} \rightarrow \text{IO} ()
\]

Appends a String value with style tags to the contents of a TextEdit widget and adjust the view to the end of the TextEdit widget. Different styles can be combined, e.g., to get bold blue text on a red background. If Bold, Italic and Underline are combined, currently all but one of these are ignored. This is an experimental function and might be changed in the future.

\[
\text{addRegionStyle} :: \text{WidgetRef} \rightarrow \text{(Int,Int)} \rightarrow \text{(Int,Int)} \rightarrow \text{Style} \rightarrow \text{GuiPort} \rightarrow \text{IO} ()
\]

Adds a style value in a region of a TextEdit widget. The region is specified a start and end position similarly to getCursorPosition. Different styles can be combined, e.g., to get bold blue text on a red background. If Bold, Italic and Underline are combined, currently all but one of these are ignored. This is an experimental function and might be changed in the future.

\[
\text{removeRegionStyle} :: \text{WidgetRef} \rightarrow \text{(Int,Int)} \rightarrow \text{(Int,Int)} \rightarrow \text{Style} \rightarrow \text{GuiPort} \rightarrow \text{IO} ()
\]

Removes a style value in a region of a TextEdit widget. The region is specified a start and end position similarly to getCursorPosition. This is an experimental function and might be changed in the future.

\[
\text{getCursorPosition} :: \text{WidgetRef} \rightarrow \text{GuiPort} \rightarrow \text{IO} \text{(Int,Int)}
\]

Get the position (line,column) of the insertion cursor in a TextEdit widget. Lines are numbered from 1 and columns are numbered from 0.

\[
\text{seeText} :: \text{WidgetRef} \rightarrow \text{(Int,Int)} \rightarrow \text{GuiPort} \rightarrow \text{IO} ()
\]

Adjust the view of a TextEdit widget so that the specified line/column character is visible. Lines are numbered from 1 and columns are numbered from 0.

\[
\text{focusInput} :: \text{WidgetRef} \rightarrow \text{GuiPort} \rightarrow \text{IO} ()
\]

Sets the input focus of this GUI to the widget referred by the first argument. This is useful for automatically selecting input entries in an application.

\[
\text{addCanvas} :: \text{WidgetRef} \rightarrow \text{[CanvasItem]} \rightarrow \text{GuiPort} \rightarrow \text{IO} ()
\]

Adds a list of canvas items to a canvas referred by the first argument.

\[
\text{popupMessage} :: \text{String} \rightarrow \text{IO} ()
\]

A simple popup message.
Cmd :: (GuiPort → IO ()) → ConfItem

A simple event handler that can be associated to a widget. The event handler takes a
GUI port as parameter in order to read or write values from/into the GUI.

Command :: (GuiPort → IO [ReconfigureItem]) → ConfItem

An event handler that can be associated to a widget. The event handler takes a GUI
port as parameter (in order to read or write values from/into the GUI) and returns a
list of widget reference/configuration pairs which is applied after the handler in order
to configure some GUI widgets.

Button :: (GuiPort → IO ()) → [ConfItem] → Widget

A button with an associated event handler which is activated if the button is pressed.

ConfigButton :: (GuiPort → IO [ReconfigureItem]) → [ConfItem] → Widget

A button with an associated event handler which is activated if the button is pressed.
The event handler is a configuration handler (see Command) that allows the configura-
tion of some widgets.

TextEditScroll :: [ConfItem] → Widget

A text edit widget with vertical and horizontal scrollbars. The argument contains the
configuration options for the text edit widget.

ListBoxScroll :: [ConfItem] → Widget

A list box widget with vertical and horizontal scrollbars. The argument contains the
configuration options for the list box widget.

CanvasScroll :: [ConfItem] → Widget

A canvas widget with vertical and horizontal scrollbars. The argument contains the
configuration options for the text edit widget.

EntryScroll :: [ConfItem] → Widget

An entry widget with a horizontal scrollbar. The argument contains the configuration
options for the entry widget.

getOpenFile :: IO String

Pops up a GUI for selecting an existing file. The file with its full path name will be
returned (or "" if the user cancels the selection).

getOpenFileWithTypes :: [(String,String)] → IO String

Pops up a GUI for selecting an existing file. The parameter is a list of pairs of file types
that could be selected. A file type pair consists of a name and an extension for that
file type. The file with its full path name will be returned (or "" if the user cancels the
selection).
getSaveFile :: IO String

Pops up a GUI for choosing a file to save some data. If the user chooses an existing file, she/he will asked to confirm to overwrite it. The file with its full path name will be returned (or "" if the user cancels the selection).

getSaveFileWithTypes :: [(String,String)] → IO String

Pops up a GUI for choosing a file to save some data. The parameter is a list of pairs of file types that could be selected. A file type pair consists of a name and an extension for that file type. If the user chooses an existing file, she/he will asked to confirm to overwrite it. The file with its full path name will be returned (or "" if the user cancels the selection).

chooseColor :: IO String

Pops up a GUI dialog box to select a color. The name of the color will be returned (or "" if the user cancels the selection).

### A.2.28 Library Integer

A collection of common operations on integer numbers. Most operations make no assumption on the precision of integers. Operation `bitNot` is necessarily an exception.

**Exported functions:**

\(^\) :: Int → Int → Int

The value of \(a ^ b\) is \(a\) raised to the power of \(b\). Fails if \(b < 0\). Executes in \(O(\log b)\) steps.

\(\text{pow} \) :: Int → Int → Int

The value of \(\text{pow} a b\) is \(a\) raised to the power of \(b\). Fails if \(b < 0\). Executes in \(O(\log b)\) steps.

\(\text{ilog} \) :: Int → Int

The value of \(\text{ilog} n\) is the floor of the logarithm in the base 10 of \(n\). Fails if \(n \leq 0\). For positive integers, the returned value is 1 less the number of digits in the decimal representation of \(n\).

\(\text{isqrt} \) :: Int → Int

The value of \(\text{isqrt} n\) is the floor of the square root of \(n\). Fails if \(n < 0\). Executes in \(O(\log n)\) steps, but there must be a better way.

\(\text{factorial} \) :: Int → Int

The value of \(\text{factorial} n\) is the factorial of \(n\). Fails if \(n < 0\).
binomial :: Int → Int → Int

The value of \( \text{binomial} \ n \ m \) is \( n(n-1)...(n-m+1)/m(m-1)...1 \). Fails if ‘\( m \leq 0 \)’ or ‘\( n < m \)’.

abs :: Int → Int

The value of \( \text{abs} \ n \) is the absolute value of \( n \).

max3 :: a → a → a → a

Returns the maximum of the three arguments.

min3 :: a → a → a → a

Returns the minimum of the three arguments.

maxlist :: [a] → a

Returns the maximum of a list of integer values. Fails if the list is empty.

minlist :: [a] → a

Returns the minimum of a list of integer values. Fails if the list is empty.

bitTrunc :: Int → Int → Int

The value of \( \text{bitTrunc} \ n \ m \) is the value of the \( n \) least significant bits of \( m \).

bitAnd :: Int → Int → Int

Returns the bitwise AND of the two arguments.

bitOr :: Int → Int → Int

Returns the bitwise inclusive OR of the two arguments.

bitNot :: Int → Int

Returns the bitwise NOT of the argument. Since integers have unlimited precision, only the 32 least significant bits are computed.

bitXor :: Int → Int → Int

Returns the bitwise exclusive OR of the two arguments.

even :: Int → Bool

Returns whether an integer is even.

odd :: Int → Bool

Returns whether an integer is odd.
A.2.29 Library IO

Library for IO operations like reading and writing files that are not already contained in the prelude.

Exported types:

data Handle

    The abstract type of a handle for a stream.

*Exported constructors:*

data IOMode

    The modes for opening a file.

*Exported constructors:*

- ReadMode :: IOMode
- WriteMode :: IOMode
- AppendMode :: IOMode

data SeekMode

    The modes for positioning with hSeek in a file.

*Exported constructors:*

- AbsoluteSeek :: SeekMode
- RelativeSeek :: SeekMode
- SeekFromEnd :: SeekMode

Exported functions:

stdin :: Handle

    Standard input stream.

stdout :: Handle

    Standard output stream.

stderr :: Handle

    Standard error stream.

openFile :: String → IOMode → IO Handle

    Opens a file in specified mode and returns a handle to it.
hClose :: Handle → IO ()

Closes a file handle and flushes the buffer in case of output file.

hFlush :: Handle → IO ()

Flushes the buffer associated to handle in case of output file.

hIsEOF :: Handle → IO Bool

Is handle at end of file?

isEOF :: IO Bool

Is standard input at end of file?

hSeek :: Handle → SeekMode → Int → IO ()

Set the position of a handle to a seekable stream (e.g., a file). If the second argument is AbsoluteSeek, SeekFromEnd, or RelativeSeek, the position is set relative to the beginning of the file, to the end of the file, or to the current position, respectively.

hWaitForInput :: Handle → Int → IO Bool

Waits until input is available on the given handle. If no input is available within t milliseconds, it returns False, otherwise it returns True.

hWaitForInputs :: [Handle] → Int → IO Int

Waits until input is available on some of the given handles. If no input is available within t milliseconds, it returns -1, otherwise it returns the index of the corresponding handle with the available data.

hWaitForInputOrMsg :: Handle → [a] → IO (Either Handle [a])

Waits until input is available on a given handles or a message in the message stream. Usually, the message stream comes from an external port. Thus, this operation implements a committed choice over receiving input from an IO handle or an external port.

Note that the implementation of this operation works only with Sicstus-Prolog 3.8.5 or higher (due to a bug in previous versions of Sicstus-Prolog).

hWaitForInputsOrMsg :: [Handle] → [a] → IO (Either Int [a])

Waits until input is available on some of the given handles or a message in the message stream. Usually, the message stream comes from an external port. Thus, this operation implements a committed choice over receiving input from IO handles or an external port.

Note that the implementation of this operation works only with Sicstus-Prolog 3.8.5 or higher (due to a bug in previous versions of Sicstus-Prolog).
hReady :: Handle → IO Bool

Checks whether an input is available on a given handle.

hGetChar :: Handle → IO Char

Reads a character from an input handle and returns it. Throws an error if the end of file has been reached.

hGetLine :: Handle → IO String

Reads a line from an input handle and returns it. Throws an error if the end of file has been reached while reading the first character. If the end of file is reached later in the line, it is treated as a line terminator and the (partial) line is returned.

hGetContents :: Handle → IO String

Reads the complete contents from an input handle and closes the input handle before returning the contents.

getContents :: IO String

Reads the complete contents from the standard input stream until EOF.

hPutChar :: Handle → Char → IO ()

Puts a character to an output handle.

hPutStr :: Handle → String → IO ()

Puts a string to an output handle.

hPutStrLn :: Handle → String → IO ()

Puts a string with a newline to an output handle.

hPrint :: Handle → a → IO ()

Converts a term into a string and puts it to an output handle.

hIsReadable :: Handle → IO Bool

Is the handle readable?

hIsWritable :: Handle → IO Bool

Is the handle writable?

hIsTerminalDevice :: Handle → IO Bool

Is the handle connected to a terminal?

A.2.30 Library IOExts

Library with some useful extensions to the IO monad.
Exported types:

data IORef

Mutable variables containing values of some type. The values are not evaluated when
they are assigned to an IORef.

Exported constructors:

Exported functions:

cmd :: String → IO (Handle,Handle,Handle)

Executes a command with a new default shell process. The standard I/O streams
of the new process (stdin, stdout, stderr) are returned as handles so that they can be
explicitly manipulated. They should be closed with IO.hClose since they are not closed
automatically when the process terminates.

cmd :: String → [String] → String → IO (Int,String,String)

Executes a command with the given arguments as a new default shell process and
provides the input via the process' stdin input stream. The exit code of the process
and the contents written to the standard I/O streams stdout and stderr are returned.

cmd :: String → IO Handle

Executes a command with a new default shell process. The input and output streams
of the new process is returned as one handle which is both readable and writable. Thus,
writing to the handle produces input to the process and output from the process can
be retrieved by reading from this handle. The handle should be closed with IO.hClose
since they are not closed automatically when the process terminates.

getFile :: String → IO String

An action that reads the complete contents of a file and returns it. This action can be
used instead of the (lazy) readFile action if the contents of the file might be changed.

updateFile :: (String → String) → String → IO ()

An action that updates the contents of a file.

cmd :: String → IO a → IO a

Forces the exclusive execution of an action via a lock file. For instance, (exclusiveIO
"myaction.lock" act) ensures that the action "act" is not executed by two processes on
the same system at the same time.

setAssoc :: String → String → IO ()

Defines a global association between two strings. Both arguments must be evaluable to
ground terms before applying this operation.
getAssoc :: String → IO (Maybe String)

Gets the value associated to a string. Nothing is returned if there does not exist an
associated value.

newIORef :: a → IO (IORef a)

Creates a new IORef with an initial values.

readIORef :: IORef a → IO a

Reads the current value of an IORef.

writeIORef :: IORef a → a → IO ()

Updates the value of an IORef.

modifyIORef :: IORef a → (a → a) → IO ()

Modify the value of an IORef.

A.2.31 Library JavaScript

A library to represent JavaScript programs.

Exported types:

data JSExp

Type of JavaScript expressions.

Exported constructors:

- • JSString :: String → JSExp
  JSString
  – string constant

- • JSInt :: Int → JSExp
  JSInt
  – integer constant

- • JSBool :: Bool → JSExp
  JSBool
  – Boolean constant

- • JSIVar :: Int → JSExp
  JSIVar
  – indexed variable
• JSIArrayIdx :: Int → Int → JSExp
  JSIArrayIdx
  – array access to index array variable

• JSOp :: String → JSExp → JSExp → JSExp
  JSOp
  – infix operator expression

• JSFCall :: String → [JSExp] → JSExp
  JSFCall
  – function call

• JSApply :: JSExp → JSExp → JSExp
  JSApply
  – function call where the function is an expression

• JSLambda :: [Int] → [JSStat] → JSExp
  JSLambda
  – (anonymous) function with indexed variables as arguments

data JSStat

Type of JavaScript statements.

Exported constructors:

• JSAssign :: JSExp → JSExp → JSStat
  JSAssign
  – assignment

• JSIf :: JSExp → [JSStat] → [JSStat] → JSStat
  JSIf
  – conditional

• JSSwitch :: JSExp → [JSBranch] → JSStat
  JSSwitch
  – switch statement

• JSPCall :: String → [JSExp] → JSStat
  JSPCall
– procedure call

• JSReturn :: JSExp → JSStat
  
  JSReturn
  
  – return statement

• JSVarDecl :: Int → JSStat
  
  JSVarDecl
  
  – local variable declaration

data JSBranch

  Exported constructors:

  • JSCase :: String → [JSStat] → JSBranch
    
    JSCase
    
    – case branch

  • JSDefault :: [JSStat] → JSBranch
    
    JSDefault
    
    – default branch

data JSFDecl

  Exported constructors:

  • JSFDecl :: String → [Int] → [JSStat] → JSFDecl

Exported functions:

showJSExp :: JSExp → String

  Shows a JavaScript expression as a string in JavaScript syntax.

showJSStat :: Int → JSStat → String

  Shows a JavaScript statement as a string in JavaScript syntax with indenting.

showJSFDecl :: JSFDecl → String

  Shows a JavaScript function declaration as a string in JavaScript syntax.

jsConsTerm :: String → [JSExp] → JSExp

  Representation of constructor terms in JavaScript.
A.2.32 Library KeyDatabase

This module provides a general interface for databases (persistent predicates) where each entry consists of a key and an info part. The key is an integer and the info is arbitrary. All functions are parameterized with a dynamic predicate that takes an integer key as a first parameter.

Exported functions:

existsDBKey :: (Int → a → Dynamic) → Int → Query Bool

Exists an entry with a given key in the database?

allDBKeys :: (Int → a → Dynamic) → Query [Int]

Query that returns all keys of entries in the database.

allDBInfos :: (Int → a → Dynamic) → Query [a]

Query that returns all infos of entries in the database.

allDBKeyInfos :: (Int → a → Dynamic) → Query [(Int,a)]

Query that returns all key/info pairs of the database.

getDBInfo :: (Int → a → Dynamic) → Int → Query (Maybe a)

Gets the information about an entry in the database.

index :: a → [a] → Int

compute the position of an entry in a list fail, if given entry is not an element.

sortByIndex :: [(Int,a)] → [a]

Sorts a given list by associated index.

groupByIndex :: [(Int,a)] → [[a]]

Sorts a given list by associated index and group for identical index. Empty lists are added for missing indexes

getDBInfos :: (Int → a → Dynamic) → [Int] → Query (Maybe [a])

Gets the information about a list of entries in the database.

deleteDBEntry :: (Int → a → Dynamic) → Int → Transaction ()

Deletes an entry with a given key in the database. No error is raised if the given key does not exist.

deleteDBEntries :: (Int → a → Dynamic) → [Int] → Transaction ()

Deletes all entries with the given keys in the database. No error is raised if some of the given keys does not exist.
updateDBEntry :: (Int \rightarrow a \rightarrow \text{Dynamic}) \rightarrow \text{Int} \rightarrow a \rightarrow \text{Transaction} ()

Overwrites an existing entry in the database.

newDBEntry :: (Int \rightarrow a \rightarrow \text{Dynamic}) \rightarrow a \rightarrow \text{Transaction} \text{Int}

Stores a new entry in the database and return the key of the new entry.

newDBKeyEntry :: (Int \rightarrow a \rightarrow \text{Dynamic}) \rightarrow \text{Int} \rightarrow a \rightarrow \text{Transaction} ()

Stores a new entry in the database under a given key. The transaction fails if the key already exists.

cleanDB :: (Int \rightarrow a \rightarrow \text{Dynamic}) \rightarrow \text{Transaction} ()

Deletes all entries in the database.

A.2.33 Library KeyDatabaseSQLite

This module provides a general interface for databases (persistent predicates) where each entry consists of a key and an info part. The key is an integer and the info is arbitrary. All functions are parameterized with a dynamic predicate that takes an integer key as a first parameter. This module reimplements the interface of the module KeyDatabase based on the SQLite database engine. In order to use it you need to have sqlite3 in your PATH environment variable or adjust the value of the constant pathsqlite3.

Programs that use the KeyDatabase module can be adjusted to use this module instead by replacing the imports of Dynamic, Database, and KeyDatabase with this module and changing the declarations of database predicates to use the function persistentSQLite instead of dynamic or persistent. This module redefines the types Dynamic, Query, and Transaction and although both implementations can be used in the same program (by importing modules qualified) they cannot be mixed.

Compared with the interface of KeyDatabase, this module lacks definitions for index, sortByIndex, groupByIndex, and runTNA and adds the functions deleteDBEntries and closeDBHandles.

Exported types:

\begin{verbatim}
type Key = Int

type KeyPred a = Int \rightarrow a \rightarrow \text{Dynamic}
\end{verbatim}

\begin{verbatim}
data Query

Queries can read but not write to the database.

Exported constructors:

data Transaction
\end{verbatim}
Transactions can modify the database and are executed atomically.

*Exported constructors:*

data Dynamic

Result type of database predicates.

*Exported constructors:*

data ColVal

Abstract type for value restrictions

*Exported constructors:*

data TError

The type of errors that might occur during a transaction.

*Exported constructors:*

- TError :: TErrorKind → String → TError

data TErrorKind

The various kinds of transaction errors.

*Exported constructors:*

- KeyNotExistsError :: TErrorKind
- NoRelationshipError :: TErrorKind
- DuplicateKeyError :: TErrorKind
- KeyRequiredError :: TErrorKind
- UniqueError :: TErrorKind
- MinError :: TErrorKind
- MaxError :: TErrorKind
- UserDefinedError :: TErrorKind
- ExecutionError :: TErrorKind
Exported functions:

`runQ :: Query a → IO a`

Runs a database query in the IO monad.

`transformQ :: (a → b) → Query a → Query b`

Applies a function to the result of a database query.

`runT :: Transaction a → IO (Either a TError)`

Runs a transaction atomically in the IO monad.

Transactions are *immediate*, which means that locks are acquired on all databases as soon as the transaction is started. After one transaction is started, no other database connection will be able to write to the database or start a transaction. Other connections can read the database during a transaction of another process.

The choice to use immediate rather than deferred transactions is conservative. It might also be possible to allow multiple simultaneous transactions that lock tables on the first database access (which is the default in SQLite). However this leads to unpredictable order in which locks are taken when multiple databases are involved. The current implementation fixes the locking order by sorting databases by their name and locking them in order immediately when a transaction begins.

More information on transactions in SQLite is available online.

`runJustT :: Transaction a → IO a`

Executes a possibly composed transaction on the current state of dynamic predicates as a single transaction. Similar to `runT` but a run-time error is raised if the execution of the transaction fails.

`getDB :: Query a → Transaction a`

Lifts a database query to the transaction type such that it can be composed with other transactions. Run-time errors that occur during the execution of the given query are transformed into transaction errors.

`returnT :: a → Transaction a`

Returns the given value in a transaction that does not access the database.

`doneT :: Transaction ()`

Returns the unit value in a transaction that does not access the database. Useful to ignore results when composing transactions.

`errorT :: TError → Transaction a`

Aborts a transaction with an error.

failT :: String → Transaction a

Aborts a transaction with a user-defined error message.

(>|>) :: Transaction a → (a → Transaction b) → Transaction b

Combines two transactions into a single transaction that executes both in sequence. The first transaction is executed, its result passed to the function which computes the second transaction, which is then executed to compute the final result.

If the first transaction is aborted with an error, the second transaction is not executed.

(>>>) :: Transaction a → Transaction b → Transaction b

Combines two transactions to execute them in sequence. The result of the first transaction is ignored.

sequenceT :: [Transaction a] → Transaction [a]

Executes a list of transactions sequentially and computes a list of all results.

sequenceT :: [Transaction a] → Transaction ()

Executes a list of transactions sequentially, ignoring their results.

mapT :: (a → Transaction b) → [a] → Transaction [b]

Applies a function that yields transactions to all elements of a list, executes the transaction sequentially, and collects their results.

mapT_ :: (a → Transaction b) → [a] → Transaction ()

Applies a function that yields transactions to all elements of a list, executes the transactions sequentially, and ignores their results.

persistentSQLite :: String → String → [String] → Int → a → Dynamic

This function is used instead of dynamic or persistent to declare predicates whose facts are stored in an SQLite database.

If the provided database or the table do not exist they are created automatically when the declared predicate is accessed for the first time.

Multiple column names can be provided if the second argument of the predicate is a tuple with a matching arity. Other record types are not supported. If no column names are provided a table with a single column called info is created. Columns of name rowid are not supported and lead to a run-time error.

existsDBKey :: (Int → a → Dynamic) → Int → Query Bool

Checks whether the predicate has an entry with the given key.

allDBKeys :: (Int → a → Dynamic) → Query [Int]
Returns a list of all stored keys. Do not use this function unless the database is small.

allDBInfos :: (Int → a → Dynamic) → Query [a]

Returns a list of all info parts of stored entries. Do not use this function unless the database is small.

allDBKeyInfos :: (Int → a → Dynamic) → Query [(Int,a)]

Returns a list of all stored entries. Do not use this function unless the database is small.

(=) :: Int → a → ColVal

Constructs a value restriction for the column given as first argument

someDBKeys :: (Int → a → Dynamic) → [ColVal] → Query [Int]

Returns a list of those stored keys where the corresponding info part matches the given value restriction. Safe to use even on large databases if the number of results is small.

someDBInfos :: (Int → a → Dynamic) → [ColVal] → Query [a]

Returns a list of those info parts of stored entries that match the given value restrictions for columns. Safe to use even on large databases if the number of results is small.

someDBKeyInfos :: (Int → a → Dynamic) → [ColVal] → Query [(Int,a)]

Returns a list of those entries that match the given value restrictions for columns. Safe to use even on large databases if the number of results is small.

someDBKeyProjections :: (Int → a → Dynamic) → [Int] → [ColVal] → Query [(Int,b)]

Returns a list of column projections on those entries that match the given value restrictions for columns. Safe to use even on large databases if the number of results is small.

getDBInfo :: (Int → a → Dynamic) → Int → Query (Maybe a)

Queries the information stored under the given key. Yields Nothing if the given key is not present.

getDBInfos :: (Int → a → Dynamic) → [Int] → Query (Maybe [a])

Queries the information stored under the given keys. Yields Nothing if a given key is not present.

deleteDBEntry :: (Int → a → Dynamic) → Int → Transaction ()

Deletes the information stored under the given key. If the given key does not exist this transaction is silently ignored and no error is raised.

deleteDBEntries :: (Int → a → Dynamic) → [Int] → Transaction ()
Deletes the information stored under the given keys. No error is raised if (some of) the keys do not exist.

\texttt{updateDBEntry :: (Int \to a \to \text{Dynamic}) \to Int \to a \to \text{Transaction} ()}

Updates the information stored under the given key. The transaction is aborted with a \texttt{KeyNotExistsError} if the given key is not present in the database.

\texttt{newDBEntry :: (Int \to a \to \text{Dynamic}) \to a \to \text{Transaction} Int}

Stores new information in the database and yields the newly generated key.

\texttt{newDBKeyEntry :: (Int \to a \to \text{Dynamic}) \to Int \to a \to \text{Transaction} ()}

Stores a new entry in the database under a given key. The transaction fails if the key already exists.

\texttt{cleanDB :: (Int \to a \to \text{Dynamic}) \to \text{Transaction} ()}

Deletes all entries from the database associated with a predicate.

\texttt{closeDBHandles :: IO ()}

Closes all database connections. Should be called when no more database access will be necessary.

\texttt{showTError :: TError \to String}

Transforms a transaction error into a string.

**A.2.34 Library KeyDB**

This module provides a general interface for databases (persistent predicates) where each entry consists of a key and an info part. The key is an integer and the info is arbitrary. All functions are parameterized with a dynamic predicate that takes an integer key as a first parameter.

Remark: This library has been revised to the library \texttt{KeyDatabase}. Thus, it might not be further supported in the future.

**Exported functions:**

\texttt{existsDBKey :: (Int \to a \to \text{Dynamic}) \to Int \to IO \text{Bool}}

Exists an entry with a given key in the database?

\texttt{allDBKeys :: (Int \to a \to \text{Dynamic}) \to IO [Int]}

Returns all keys of entries in the database.

\texttt{getDBInfo :: (Int \to a \to \text{Dynamic}) \to Int \to IO a}

Gets the information about an entry in the database.

\texttt{index :: a \to [a] \to Int}
compute the position of an entry in a list fail, if given entry is not an element.

sortByIndex :: [(Int,a)] → [a]
Sorts a given list by associated index.

groupByIndex :: [(Int,a)] → [[a]]
Sorts a given list by associated index and group for identical index. Empty lists are added for missing indexes.

getDBInfos :: (Int → a → Dynamic) → [Int] → IO [a]
Gets the information about a list of entries in the database.

deleteDBEntry :: (Int → a → Dynamic) → Int → IO ()
Deletes an entry with a given key in the database.

updateDBEntry :: (Int → a → Dynamic) → Int → a → IO ()
Overwrites an existing entry in the database.

newDBEntry :: (Int → a → Dynamic) → a → IO Int
Stores a new entry in the database and return the key of the new entry.

cleanDB :: (Int → a → Dynamic) → IO ()
Deletes all entries in the database.

A.2.35 Library List
Library with some useful operations on lists.

Exported functions:

elemIndex :: a → [a] → Maybe Int
Returns the index \( i \) of the first occurrence of an element in a list as (\( \text{Just } i \)), otherwise \( \text{Nothing} \) is returned.

elemIndices :: a → [a] → [Int]
Returns the list of indices of occurrences of an element in a list.

find :: (a → Bool) → [a] → Maybe a
Returns the first element \( e \) of a list satisfying a predicate as (\( \text{Just } e \)), otherwise \( \text{Nothing} \) is returned.

findIndex :: (a → Bool) → [a] → Maybe Int
Returns the index \( i \) of the first occurrences of a list element satisfying a predicate as \( \text{Just } i \), otherwise \text{Nothing} \ is returned.

\[
\text{findIndices} :: (a \to \text{Bool}) \to [a] \to [\text{Int}]
\]

Returns the list of indices of list elements satisfying a predicate.

\[
\text{nub} :: [a] \to [a]
\]

Removes all duplicates in the argument list.

\[
\text{nubBy} :: (a \to a \to \text{Bool}) \to [a] \to [a]
\]

Removes all duplicates in the argument list according to an equivalence relation.

\[
\text{delete} :: a \to [a] \to [a]
\]

Deletes the first occurrence of an element in a list.

\[
\text{deleteBy} :: (a \to a \to \text{Bool}) \to a \to [a] \to [a]
\]

Deletes the first occurrence of an element in a list according to an equivalence relation.

\[
(\setminus) :: [a] \to [a] \to [a]
\]

Computes the difference of two lists.

\[
\text{union} :: [a] \to [a] \to [a]
\]

Computes the union of two lists.

\[
\text{unionBy} :: (a \to a \to \text{Bool}) \to [a] \to [a] \to [a]
\]

Computes the union of two lists according to the given equivalence relation.

\[
\text{intersect} :: [a] \to [a] \to [a]
\]

Computes the intersection of two lists.

\[
\text{intersectBy} :: (a \to a \to \text{Bool}) \to [a] \to [a] \to [a]
\]

Computes the intersection of two lists according to the given equivalence relation.

\[
\text{intersperse} :: a \to [a] \to [a]
\]

Puts a separator element between all elements in a list.

Example: \( \text{intersperse } 9 \ [1,2,3,4] \) = \( [1,9,2,9,3,9,4] \)

\[
\text{intercalate} :: [a] \to [[a]] \to [a]
\]

\( \text{intercalate } xs \ xss \) is equivalent to \( \text{concat } (\text{intersperse } xs \ xss) \). It inserts the list \( xs \) in between the lists in \( xss \) and concatenates the result.

\[
\text{transpose} :: [[a]] \to [[a]]
\]
Transposes the rows and columns of the argument.

Example: \((\text{transpose } [[1,2,3],[4,5,6]]) = [[1,4],[2,5],[3,6]]\)

\textbf{permutations :: [a] → [[a]]}

Returns the list of all permutations of the argument.

\textbf{partition :: (a → Bool) → [a] → ([a],[a])}

Partitions a list into a pair of lists where the first list contains those elements that satisfy the predicate argument and the second list contains the remaining arguments.

Example: \((\text{partition (<4)}</4>)\)

\textbf{group :: [a] → [[a]]}

Splits the list argument into a list of lists of equal adjacent elements.

Example: \((\text{group } [1,2,2,3,3,3,4]) = [[1],[2,2],[3,3,3],[4]]\)

\textbf{groupBy :: (a → a → Bool) → [a] → [[a]]}

Splits the list argument into a list of lists of related adjacent elements.

\textbf{splitOn :: [a] → [a] → [[a]]}

Breaks the second list argument into pieces separated by the first list argument, consuming the delimiter. An empty delimiter is invalid, and will cause an error to be raised.

\textbf{split :: (a → Bool) → [a] → [[a]]}

Splits a list into components delimited by separators, where the predicate returns True for a separator element. The resulting components do not contain the separators. Two adjacent separators result in an empty component in the output.

\(\text{split (==a) "aabbaca" == ["","","bb","c",""]}\) \(\text{split (==a) "" == ["]"}\)

\textbf{inits :: [a] → [[a]]}

Returns all initial segments of a list, starting with the shortest. Example: \(\text{inits [1,2,3] = [[],[1],[1,2],[1,2,3]]}\)

\textbf{tails :: [a] → [[a]]}

Returns all final segments of a list, starting with the longest. Example: \(\text{tails [1,2,3] = [[1,2,3],[2,3],[3],[]]}\)

\textbf{replace :: a → Int → [a] → [a]}

Replaces an element in a list.

\textbf{isPrefixOf :: [a] → [a] → Bool}
Checks whether a list is a prefix of another.

\[\text{isSuffixOf} :: [a] \rightarrow [a] \rightarrow \text{Bool}\]

Checks whether a list is a suffix of another.

\[\text{isInfixOf} :: [a] \rightarrow [a] \rightarrow \text{Bool}\]

Checks whether a list is contained in another.

\[\text{sortBy} :: (a \rightarrow a \rightarrow \text{Bool}) \rightarrow [a] \rightarrow [a]\]

Sorts a list w.r.t. an ordering relation by the insertion method.

\[\text{insertBy} :: (a \rightarrow a \rightarrow \text{Bool}) \rightarrow a \rightarrow [a] \rightarrow [a]\]

Inserts an object into a list according to an ordering relation.

\[\text{last} :: [a] \rightarrow a\]

Returns the last element of a non-empty list.

\[\text{init} :: [a] \rightarrow [a]\]

Returns the input list with the last element removed.

\[\text{sum} :: [\text{Int}] \rightarrow \text{Int}\]

Returns the sum of a list of integers.

\[\text{product} :: [\text{Int}] \rightarrow \text{Int}\]

Returns the product of a list of integers.

\[\text{maximum} :: [a] \rightarrow a\]

Returns the maximum of a non-empty list.

\[\text{maximumBy} :: (a \rightarrow a \rightarrow \text{Ordering}) \rightarrow [a] \rightarrow a\]

Returns the maximum of a non-empty list according to the given comparison function.

\[\text{minimum} :: [a] \rightarrow a\]

Returns the minimum of a non-empty list.

\[\text{minimumBy} :: (a \rightarrow a \rightarrow \text{Ordering}) \rightarrow [a] \rightarrow a\]

Returns the minimum of a non-empty list according to the given comparison function.

\[\text{scanl} :: (a \rightarrow b \rightarrow a) \rightarrow a \rightarrow [b] \rightarrow [a]\]

\[\text{scanl1} :: (a \rightarrow a \rightarrow a) \rightarrow [a] \rightarrow [a]\]

\[\text{scanl}\] is similar to \[\text{foldl}\], but returns a list of successive reduced values from the left:

\[\text{scanl}\ f\ z\ [x1, x2, \ldots]\ ==\ [z, z\ f\ x1, (z\ f\ x1)\ f\ x2, \ldots]\]
\textit{scanl1} is a variant of \textit{scanl} that has no starting value argument: \(\text{scanl1 } f \ [x_1, x_2, ...] == [x_1, x_1 \ f \ x_2, ...]\)

\textit{scanr} :: \((a \rightarrow b \rightarrow b) \rightarrow b \rightarrow [a] \rightarrow [b]\)

\textit{scanr} is the right-to-left dual of \textit{scanl}.

\textit{scanr1} :: \((a \rightarrow a \rightarrow a) \rightarrow [a] \rightarrow [a]\)

\textit{scanr1} is a variant of \textit{scanr} that has no starting value argument.

\textit{mapAccumL} :: \((a \rightarrow b \rightarrow (a,c)) \rightarrow a \rightarrow [b] \rightarrow (a,[c])\)

The \textit{mapAccumL} function behaves like a combination of \textit{map} and \textit{foldl}; it applies a function to each element of a list, passing an accumulating parameter from left to right, and returning a final value of this accumulator together with the new list.

\textit{mapAccumR} :: \((a \rightarrow b \rightarrow (a,c)) \rightarrow a \rightarrow [b] \rightarrow (a,[c])\)

The \textit{mapAccumR} function behaves like a combination of \textit{map} and \textit{foldr}; it applies a function to each element of a list, passing an accumulating parameter from right to left, and returning a final value of this accumulator together with the new list.

\textit{cycle} :: \([a] \rightarrow [a]\)

Builds an infinite list from a finite one.

\textit{unfoldr} :: \((a \rightarrow \text{Maybe } (b,a)) \rightarrow a \rightarrow [b]\)

Builds a list from a seed value.

\textbf{A.2.36 Library \textit{Maybe}}

Library with some useful functions on the \textit{Maybe} datatype.

\textbf{Exported functions:}

\textit{isJust} :: \textit{Maybe } a \rightarrow \textit{Bool}

Return \texttt{True} iff the argument is of the form \texttt{Just } _.

\textit{isNothing} :: \textit{Maybe } a \rightarrow \textit{Bool}

Return \texttt{True} iff the argument is of the form \texttt{Nothing}.

\textit{fromJust} :: \textit{Maybe } a \rightarrow a

Extract the argument from the \texttt{Just} constructor and throw an error if the argument is \texttt{Nothing}.

\textit{fromMaybe} :: a \rightarrow \textit{Maybe } a \rightarrow a
Extract the argument from the \texttt{Just} constructor or return the provided default value if the argument is \texttt{Nothing}.

\begin{verbatim}
listToMaybe :: [a] \to \text{Maybe} a
\end{verbatim}

Return \texttt{Nothing} on an empty list or \texttt{Just} \(x\) where \(x\) is the first list element.

\begin{verbatim}
maybeToList :: \text{Maybe} a \to [a]
\end{verbatim}

Return an empty list for \texttt{Nothing} or a singleton list for \texttt{Just} \(x\).

\begin{verbatim}
catMaybes :: [\text{Maybe} a] \to [a]
\end{verbatim}

Return the list of all \texttt{Just} values.

\begin{verbatim}
mapMaybe :: (a \to \text{Maybe} b) \to [a] \to [b]
\end{verbatim}

Apply a function which may throw out elements using the \texttt{Nothing} constructor to a list of elements.

\begin{verbatim}
(\triangleright\triangleright\triangleright) :: \text{Maybe} a \to (a \to \text{Maybe} b) \to \text{Maybe} b
\end{verbatim}

Monadic \texttt{bind} for \texttt{Maybe}. \texttt{Maybe} can be interpreted as a monad where \texttt{Nothing} is interpreted as the error case by this monadic binding.

\begin{verbatim}
sequenceMaybe :: [\text{Maybe} a] \to \text{Maybe} [a]
\end{verbatim}

Monadic \texttt{sequence} for \texttt{Maybe}.

\begin{verbatim}
mapMMaybe :: (a \to \text{Maybe} b) \to [a] \to \text{Maybe} [b]
\end{verbatim}

Monadic \texttt{map} for \texttt{Maybe}.

\begin{verbatim}
mplus :: \text{Maybe} a \to \text{Maybe} a \to \text{Maybe} a
\end{verbatim}

Combine two \texttt{Maybe}s, returning the first \texttt{Just} value, if any.

A.2.37 Library NamedSocket

Library to support network programming with sockets that are addressed by symbolic names. In contrast to raw sockets (see library \texttt{Socket}), this library uses the Curry Port Name Server to provide sockets that are addressed by symbolic names rather than numbers. In standard applications, the server side uses the operations \texttt{listenOn} and \texttt{socketAccept} to provide some service on a named socket, and the client side uses the operation \texttt{connectToSocket} to request a service.

Exported types:

\begin{verbatim}
data Socket
\end{verbatim}

Abstract type for named sockets.

\begin{footnotesize}
\textit{Exported constructors:}
\end{footnotesize}
Exported functions:

listenOn :: String → IO Socket

Creates a server side socket with a symbolic name.

socketAccept :: Socket → IO (String,Handle)

Returns a connection of a client to a socket. The connection is returned as a pair consisting of a string identifying the client (the format of this string is implementation-dependent) and a handle to a stream communication with the client. The handle is both readable and writable.

waitForSocketAccept :: Socket → Int → IO (Maybe (String,Handle))

Waits until a connection of a client to a socket is available. If no connection is available within the time limit, it returns Nothing, otherwise the connection is returned as a pair consisting of a string identifying the client (the format of this string is implementation-dependent) and a handle to a stream communication with the client.

sClose :: Socket → IO ()

Closes a server socket.

socketName :: Socket → String

Returns a the symbolic name of a named socket.

connectToSocketRepeat :: Int → IO a → Int → String → IO (Maybe Handle)

Waits for connection to a Unix socket with a symbolic name. In contrast to connectToSocket, this action waits until the socket has been registered with its symbolic name.

connectToSocketWait :: String → IO Handle

Waits for connection to a Unix socket with a symbolic name and return the handle of the connection. This action waits (possibly forever) until the socket with the symbolic name is registered.

connectToSocket :: String → IO Handle

Creates a new connection to an existing(!) Unix socket with a symbolic name. If the symbolic name is not registered, an error is reported.

A.2.38 Library Parser

Library with functional logic parser combinators.
Exported types:

\[
\text{type } \text{Parser } a = [a] \to [a]
\]

\[
\text{type } \text{ParserRep } a \ b = a \to [b] \to [b]
\]

Exported functions:

\[
(\langle | \rangle) :: ([a] \to [a]) \to ([a] \to [a]) \to [a] \to [a]
\]

Combines two parsers without representation in an alternative manner.

\[
(\langle || \rangle) :: (a \to [b] \to [b]) \to (a \to [b] \to [b]) \to a \to [b] \to [b]
\]

Combines two parsers with representation in an alternative manner.

\[
(\langle * \rangle) :: ([a] \to [a]) \to ([a] \to [a]) \to [a] \to [a]
\]

Combines two parsers (with or without representation) in a sequential manner.

\[
(>>>) :: ([a] \to [a]) \to b \to b \to [a] \to [a]
\]

Attaches a representation to a parser without representation.

\[
\text{empty} :: [a] \to [a]
\]

The empty parser which recognizes the empty word.

\[
\text{terminal} :: a \to [a] \to [a]
\]

A parser recognizing a particular terminal symbol.

\[
\text{satisfy} :: (a \to \text{Bool}) \to a \to [a] \to [a]
\]

A parser (with representation) recognizing a terminal satisfying a given predicate.

\[
\text{star} :: (a \to [b] \to [b]) \to [a] \to [b] \to [b]
\]

A star combinator for parsers. The returned parser repeats zero or more times a parser \(p\) with representation and returns the representation of all parsers in a list.

\[
\text{some} :: (a \to [b] \to [b]) \to [a] \to [b] \to [b]
\]

A some combinator for parsers. The returned parser repeats the argument parser (with representation) at least once.

A.2.39 Library Ports

Library for distributed programming with ports. This paper\(^{10}\) contains a description of the basic ideas behind this library.

\(^{10}\)http://www.informatik.uni-kiel.de/~mh/papers/PPDP99.html
Exported types:

data Port

    The internal constructor for the port datatype is not visible to the user.

Exported constructors:

data SP_Msg

    A "stream port" is an adaption of the port concept to model the communication with
bidirectional streams, i.e., a stream port is a port connection to a bidirectional stream
(e.g., opened by openProcessPort) where the communication is performed via the fol-
lowing stream port messages.

Exported constructors:

• SP_Put :: String → SP_Msg
    SP_Put s
    -- write the argument s on the output stream

• SP_GetLine :: String → SP_Msg
    SP_GetLine s
    -- unify the argument s with the next text line of the input stream

• SP_GetChar :: Char → SP_Msg
    SP_GetChar c
    -- unify the argument c with the next character of the input stream

• SP_EOF :: Bool → SP_Msg
    SP_EOF b
    -- unify the argument b with True if we are at the end of the input stream, otherwise with
    False

• SP_Close :: SP_Msg
    SP_Close
    -- close the input/output streams
Exported functions:

openPort :: Port a → [a] → Success

Opens an internal port for communication.

send :: a → Port a → Success

Sends a message to a port.

doSsend :: a → Port a → IO ()

I/O action that sends a message to a port.

ping :: Int → Port a → IO (Maybe Int)

Checks whether port p is still reachable.

timeoutOnStream :: Int → [a] → Maybe [a]

Checks for instantiation of a stream within some amount of time.

openProcessPort :: String → IO (Port SP_Msg)

Opens a new connection to a process that executes a shell command.

openNamedPort :: String → IO [a]

Opens an external port with a symbolic name.

connectPortRepeat :: Int → IO a → Int → String → IO (Maybe (Port b))

Waits for connection to an external port. In contrast to connectPort, this action waits until the external port has been registered with its symbolic name.

connectPortWait :: String → IO (Port a)

Waits for connection to an external port and return the connected port. This action waits (possibly forever) until the external port is registered.

connectPort :: String → IO (Port a)

Connects to an external port. The external port must be already registered, otherwise an error is reported.

choiceSPEP :: Port SP_Msg → [a] → Either String [a]

This function implements a committed choice over the receiving of messages via a stream port and an external port.

Note that the implementation of choiceSPEP works only with Sicstus-Prolog 3.8.5 or higher (due to a bug in previous versions of Sicstus-Prolog).

newObject :: (a → [b] → Success) → a → Port b → Success
Creates a new object (of type State -> [msg] -> Success) with an initial state and a port to which messages for this object can be sent.

\[
\text{newNamedObject :: (a \rightarrow [b] \rightarrow \text{Success}) \rightarrow a \rightarrow \text{String} \rightarrow \text{IO} ()}
\]

Creates a new object (of type State -> [msg] -> Success) with a symbolic port name to which messages for this object can be sent.

\[
\text{runNamedServer :: ([a] \rightarrow \text{IO} b) \rightarrow \text{String} \rightarrow \text{IO} b}
\]

Runs a new server (of type [msg] -> IO a) on a named port to which messages can be sent.

A.2.40 Library Pretty

This library provides pretty printing combinators. The interface is that of Daan Leijen’s library (fill, fillBreak and indent are missing) with a linear-time, bounded implementation by Olaf Chitil.

Exported types:

\[
\text{data Doc}
\]

The abstract data type Doc represents pretty documents.

Exported constructors:

Exported functions:

\[
\text{empty :: Doc}
\]

The empty document is, indeed, empty. Although empty has no content, it does have a height of 1 and behaves exactly like (text "") (and is therefore not a unit of <$>).

\[
\text{isEmpty :: Doc \rightarrow Bool}
\]

Is the document empty?

\[
\text{text :: String \rightarrow Doc}
\]

The document (text s) contains the literal string s. The string shouldn’t contain any newline (\n) characters. If the string contains newline characters, the function string should be used.

\[
\text{linesep :: String \rightarrow Doc}
\]

The document (linesep s) advances to the next line and indents to the current nesting level. Document (linesep s) behaves like (text s) if the line break is undone by group.

\[
\text{line :: Doc}
\]
The line document advances to the next line and indents to the current nesting level. Document line behaves like \(\text{text " "}\) if the line break is undone by group.

**linebreak :: Doc**

The linebreak document advances to the next line and indents to the current nesting level. Document linebreak behaves like empty if the line break is undone by group.

**softline :: Doc**

The document softline behaves like \(\text{space}\) if the resulting output fits the page, otherwise it behaves like \(\text{line}\).

\[
\text{softline} = \text{group line}
\]

**softbreak :: Doc**

The document softbreak behaves like \(\text{empty}\) if the resulting output fits the page, otherwise it behaves like \(\text{line}\).

\[
\text{softbreak} = \text{group linebreak}
\]

**group :: Doc → Doc**

The group combinator is used to specify alternative layouts. The document \((\text{group x})\) undoes all line breaks in document \(x\). The resulting line is added to the current line if that fits the page. Otherwise, the document \(x\) is rendered without any changes.

**nest :: Int → Doc → Doc**

The document \((\text{nest i d})\) renders document \(d\) with the current indentation level increased by \(i\) (See also \text{hang}, \text{align} and \text{indent}).

\[
\text{nest 2 (text "hello" <$> text "world") <$> text "!"}
\]

outputs as:

hello
  world
!

**hang :: Int → Doc → Doc**

The hang combinator implements hanging indentation. The document \((\text{hang i d})\) renders document \(d\) with a nesting level set to the current column plus \(i\). The following example uses hanging indentation for some text:

\[
\text{test} = \text{hang 4}
\]

  \[
  \text{(fillSep}
  \text{(map text}
  \text{(words "the hang combinator indents these words !")))}
  \]
Which lays out on a page with a width of 20 characters as:

the hang combinator
  indents these
  words!

The hang combinator is implemented as:

hang \ i \ x \ = \ align \ (nest \ i \ x)

align :: Doc \ \rightarrow \ \ Doc

The document (align \ d) renders document ‘d with the nesting level set to the current column. It is used for example to implement hang.

As an example, we will put a document right above another one, regardless of the current nesting level:

x $$ y \ = \ align \ (x \ <$> \ y)

\text{test} \ = \ \text{text} \ "\text{hi}\" \ <$> \ (\text{text} \ "\text{nice}\" \ $$ \ \text{text} \ "\text{world}\")

which will be layed out as:

hi nice

world

combine :: Doc \ \rightarrow \ \ Doc \ \rightarrow \ \ Doc \ \rightarrow \ \ Doc

The document (combine \ x \ l \ r) encloses document \ x between documents \ l \ and \ r using ($>$).

\text{combine} \ x \ l \ r \ = \ l \ <$> \ x \ <$> \ r

($>$) :: Doc \ \rightarrow \ \ Doc \ \rightarrow \ \ Doc

The document (x <$> y) concatenates document x and document y. It is an associative operation having empty as a left and right unit.

($<$>) :: Doc \ \rightarrow \ \ Doc \ \rightarrow \ \ Doc

The document (x $<$> y) concatenates document x and y with a \text{space} in between.

($<$$> \ :) :: Doc \ \rightarrow \ \ Doc \ \rightarrow \ \ Doc

The document (x <$>$ y) concatenates document x and y with a \text{line} in between.
The document $(x <\$> y)$ concatenates document $x$ and $y$ with a blank line in between.

$(<\>/>) :: \text{Doc} \rightarrow \text{Doc} \rightarrow \text{Doc}$

The document $(x <\/> y)$ concatenates document $x$ and $y$ with a softline in between. This effectively puts $x$ and $y$ either next to each other (with a space in between) or underneath each other.

$(<$$>) :: \text{Doc} \rightarrow \text{Doc} \rightarrow \text{Doc}$

The document $(x <$$ y)$ concatenates document $x$ and $y$ with a linebreak in between.

$(<\//>) :: \text{Doc} \rightarrow \text{Doc} \rightarrow \text{Doc}$

The document $(x <\//> y)$ concatenates document $x$ and $y$ with a softbreak in between. This effectively puts $x$ and $y$ either right next to each other or underneath each other.

$\text{compose} :: (\text{Doc} \rightarrow \text{Doc} \rightarrow \text{Doc}) \rightarrow \left[ \text{Doc} \right] \rightarrow \text{Doc}$

The document $(\text{compose} f \text{xs})$ concatenates all documents $\text{xs}$ with function $f$. Function $f$ should be like $(<\+>)$, $(<$$>)$ and so on.

$hsep :: \left[ \text{Doc} \right] \rightarrow \text{Doc}$

The document $(hsep \text{xs})$ concatenates all documents $\text{xs}$ horizontally with $(<\+>)$.

$vsep :: \left[ \text{Doc} \right] \rightarrow \text{Doc}$

The document $(vsep \text{xs})$ concatenates all documents $\text{xs}$ vertically with $(<$$>)$. If a group undoes the line breaks inserted by $vsep$, all documents are separated with a space.

```haskell
someText = map text (words ("text to lay out"))
test = text "some" <+> vsep someText
```

This is laid out as:

```
some text
to
lay
out
```

The $\text{align}$ combinator can be used to align the documents under their first element:

```haskell
test = text "some" <+> align (vsep someText)
```

This is printed as:
some text
to
lay
out

fillSep :: [Doc] → Doc

The document (fillSep xs) concatenates documents xs horizontally with (<+>) as long as its fits the page, than inserts a line and continues doing that for all documents in xs.

fillSep xs = foldr (</>) empty xs

sep :: [Doc] → Doc

The document (sep xs) concatenates all documents xs either horizontally with (<+>), if it fits the page, or vertically with (<$>).

sep xs = group (vsep xs)

hcat :: [Doc] → Doc

The document (hcat xs) concatenates all documents xs horizontally with (<>).

vcat :: [Doc] → Doc

The document (vcat xs) concatenates all documents xs vertically with (<$>). If a group undoes the line breaks inserted by vcat, all documents are directly concatenated.

fillCat :: [Doc] → Doc

The document (fillCat xs) concatenates documents xs horizontally with (<>) as long as its fits the page, than inserts a linebreak and continues doing that for all documents in xs.

fillCat xs = foldr (</>) empty xs

cat :: [Doc] → Doc

The document (cat xs) concatenates all documents xs either horizontally with (<>), if it fits the page, or vertically with (<$>).

cat xs = group (vcat xs)

punctuate :: Doc → [Doc] → [Doc]

(punctuate p xs) concatenates all documents xs with document p except for the last document.

someText = map text ["words","in","a","tuple"]

test = parens (align (cat (punctuate comma someText)))
This is layed out on a page width of 20 as:

(words, in, a, tuple)

But when the page width is 15, it is layed out as:

(words, in, a, tuple)

(If you want put the commas in front of their elements instead of at the end, you should use tupled or, in general, encloseSep.)

encloseSep :: Doc → Doc → Doc → [Doc] → Doc

The document (encloseSep l r sep xs) concatenates the documents xs seperated by sep and encloses the resulting document by l and r.

The documents are rendered horizontally if that fits the page. Otherwise they are aligned vertically. All seperators are put in front of the elements.

For example, the combinator list can be defined with enclose:

list xs = encloseSep lbracket rbracket comma xs

test = text "list" <+> (list (map int [10,200,3000]))

Which is layed out with a page width of 20 as:

list [10,200,3000]

But when the page width is 15, it is layed out as:

list [10,200,3000]


The document (hEncloseSep l r sep xs) concatenates the documents xs seperated by sep and encloses the resulting document by l and r.

The documents are rendered horizontally.

The document \((\text{fillEncloseSep } l \ r \ \text{sep} \ xs)\) concatenates the documents \(xs\) separated by \(\text{sep}\) and encloses the resulting document by \(l\) and \(r\).

The documents are rendered horizontally if that fits the page. Otherwise they are aligned vertically. All separators are put in front of the elements.

\textbf{fillEncloseSepSpaced :: Doc \rightarrow Doc \rightarrow Doc \rightarrow [Doc] \rightarrow Doc}

The document \((\text{fillEncloseSepSpaced } l \ r \ \text{sep} \ xs)\) concatenates the documents \(xs\) separated by \(\text{sep}\) and encloses the resulting document by \(l\) and \(r\). In addition, after each occurrence of \(\text{sep}\), after \(l\), and before \(r\), a \textbf{space} is inserted.

The documents are rendered horizontally if that fits the page. Otherwise, they are aligned vertically. All separators are put in front of the elements.

\textbf{list :: [Doc] \rightarrow Doc}

The document \((\text{list } xs)\) comma seperates the documents \(xs\) and encloses them in square brackets. The documents are rendered horizontally if that fits the page. Otherwise they are aligned vertically. All comma separators are put in front of the elements.

\textbf{listSpaced :: [Doc] \rightarrow Doc}

Spaced version of \textbf{list}

\textbf{tupled :: [Doc] \rightarrow Doc}

The document \((\text{tupled } xs)\) comma seperates the documents \(xs\) and encloses them in parenthesis. The documents are rendered horizontally if that fits the page. Otherwise they are aligned vertically. All comma separators are put in front of the elements.

\textbf{tupledSpaced :: [Doc] \rightarrow Doc}

Spaced version of \textbf{tupled}

\textbf{semiBraces :: [Doc] \rightarrow Doc}

The document \((\text{semiBraces } xs)\) seperates the documents \(xs\) with semi colons and encloses them in brace. The documents are rendered horizontally if that fits the page. Otherwise they are aligned vertically. All semi colons are put in front of the elements.

\textbf{semiBracesSpaced :: [Doc] \rightarrow Doc}

Spaced version of \textbf{semiBraces}

\textbf{enclose :: Doc \rightarrow Doc \rightarrow Doc \rightarrow Doc}

The document \((\text{enclose } l \ r \ x)\) encloses document \(x\) between documents \(l\) and \(r\) using \((<>).\)

\textbf{enclose } l \ r \ x = l \ < > \ x \ < > \ r

\textbf{quotes :: Doc \rightarrow Doc}
Document (squotes x) encloses document x with single quotes "'".

dquotes :: Doc → Doc

Document (dquotes x) encloses document x with double quotes ".

bquotes :: Doc → Doc

Document (bquotes x) encloses document x with ' quotes.

parens :: Doc → Doc

Document (parens x) encloses document x in parenthesis, "(" and ")".

parensIf :: Bool → Doc → Doc

Document (parens x) encloses document x in parenthesis, "(" and ")", iff the condition is true.

angles :: Doc → Doc

Document (angles x) encloses document x in angles, "<" and ">".

braces :: Doc → Doc

Document (braces x) encloses document x in braces, "{" and "}".

brackets :: Doc → Doc

Document (brackets x) encloses document x in square brackets, "[" and "]".

char :: Char → Doc

The document (char c) contains the literal character c. The character shouldn’t be a newline (\n), the function line should be used for line breaks.

string :: String → Doc

The document (string s) concatenates all characters in s using line for newline characters and char for all other characters. It is used instead of text whenever the text contains newline characters.

int :: Int → Doc

The document (int i) shows the literal integer i using text.

float :: Float → Doc

The document (float f) shows the literal float f using text.

lparen :: Doc

The document lparen contains a left parenthesis, "(".

rparen :: Doc
The document rparen contains a right parenthesis, ")".

\texttt{langle :: Doc}

The document langle contains a left angle, "<".

\texttt{rangle :: Doc}

The document rangle contains a right angle, ">".

\texttt{lbrace :: Doc}

The document lbrace contains a left brace, "{".

\texttt{rbrace :: Doc}

The document rbrace contains a right brace, "}".

\texttt{lbracket :: Doc}

The document lbracket contains a left square bracket, "[".

\texttt{rbracket :: Doc}

The document rbracket contains a right square bracket, "]".

\texttt{squote :: Doc}

The document squote contains a single quote, "'".

\texttt{dquote :: Doc}

The document dquote contains a double quote, "".

\texttt{semi :: Doc}

The document semi contains a semi colon, ";".

\texttt{colon :: Doc}

The document colon contains a colon, ":".

\texttt{comma :: Doc}

The document comma contains a comma, ",".

\texttt{space :: Doc}

The document space contains a single space, " ".

\texttt{x <> y = x <> space <> y}

\texttt{dot :: Doc}

The document dot contains a single dot, ".".

138
The document contains a back slash, "\".

The document contains an equal sign, "=".

The document contains an arrow sign, "->".

The document contains a double arrow sign, "=>".

The document contains a double colon sign, "::".

The document contains a vertical bar sign, "|".

pretty :: Int → Doc → String

\((\text{pretty } w \ d)\) pretty prints document \(d\) with a page width of \(w\) characters

A.2.41 Library Profile

Preliminary library to support profiling.

Exported types:

data ProcessInfo

The data type for representing information about the state of a Curry process.

Exported constructors:

• RunTime :: ProcessInfo
  RunTime
  – the run time in milliseconds

• ElapsedTime :: ProcessInfo
  ElapsedTime
  – the elapsed time in milliseconds

• Memory :: ProcessInfo
  Memory
- the total memory in bytes

- Code :: ProcessInfo
  Code
  - the size of the code area in bytes

- Stack :: ProcessInfo
  Stack
  - the size of the local stack for recursive functions in bytes

- Heap :: ProcessInfo
  Heap
  - the size of the heap to store term structures in bytes

- Choices :: ProcessInfo
  Choices
  - the size of the choicepoint stack

- GarbageCollections :: ProcessInfo
  GarbageCollections
  - the number of garbage collections performed

Exported functions:

getProcessInfos :: IO [(ProcessInfo,Int)]

Returns various informations about the current state of the Curry process. Note that the returned values are very implementation dependent so that one should interpret them with care!

garbageCollectorOff :: IO ()

Turns off the garbage collector of the run-time system (if possible). This could be useful to get more precise data of memory usage.

garbageCollectorOn :: IO ()

Turns on the garbage collector of the run-time system (if possible).

garbageCollect :: IO ()

Invoke the garbage collector (if possible). This could be useful before run-time critical operations.

showMemInfo :: [(ProcessInfo,Int)] → String
Get a human readable version of the memory situation from the process infos.

\[ \text{print} \text{MemInfo} :: \text{IO } () \]

Print a human readable version of the current memory situation of the Curry process.

\[ \text{profileTime} :: \text{IO } a \rightarrow \text{IO } a \]

Print the time needed to execute a given IO action.

\[ \text{profileTimeNF} :: a \rightarrow \text{IO } () \]

Evaluates the argument to normal form and print the time needed for this evaluation.

\[ \text{profileSpace} :: \text{IO } a \rightarrow \text{IO } a \]

Print the time and space needed to execute a given IO action. During the execution, the garbage collector is turned off to get the total space usage.

\[ \text{profileSpaceNF} :: a \rightarrow \text{IO } () \]

Evaluates the argument to normal form and print the time and space needed for this evaluation. During the evaluation, the garbage collector is turned off to get the total space usage.

\[ \text{evalTime} :: a \rightarrow a \]

Evaluates the argument to normal form (and return the normal form) and print the time needed for this evaluation on standard error. Included for backward compatibility only, use profileTime!

\[ \text{evalSpace} :: a \rightarrow a \]

Evaluates the argument to normal form (and return the normal form) and print the time and space needed for this evaluation on standard error. During the evaluation, the garbage collector is turned off. Included for backward compatibility only, use profileSpace!

### A.2.42 Library Prolog

A library defining a representation for Prolog programs together with a simple pretty printer. It does not cover all aspects of Prolog but might be useful for applications generating Prolog programs.

**Exported types:**

**data** \text{PlClause}  

A Prolog clause is either a program clause consisting of a head and a body, or a directive or a query without a head.

*Exported constructors:*
• PlClause :: String → [PlTerm] → [PlGoal] → PlClause

• PlDirective :: [PlGoal] → PlClause

• PlQuery :: [PlGoal] → PlClause

data PlGoal

A Prolog goal is a literal, a negated goal, or a conditional.

Exported constructors:

• PlLit :: String → [PlTerm] → PlGoal

• PlNeg :: [PlGoal] → PlGoal

• PlCond :: [PlGoal] → [PlGoal] → [PlGoal] → PlGoal

data PlTerm

A Prolog term is a variable, atom, number, or structure.

Exported constructors:

• PlVar :: String → PlTerm

• PlAtom :: String → PlTerm

• PlInt :: Int → PlTerm

• PlFloat :: Float → PlTerm

• PlStruct :: String → [PlTerm] → PlTerm

Exported functions:

plList :: [PlTerm] → PlTerm

A Prolog list of Prolog terms.

showPlProg :: [PlClause] → String

Shows a Prolog program in standard Prolog syntax.

showPlClause :: PlClause → String

showPlGoals :: [PlGoal] → String

showPlGoal :: PlGoal → String

showPlTerm :: PlTerm → String
A.2.43 Library PropertyFile

A library to read and update files containing properties in the usual equational syntax, i.e., a property is defined by a line of the form prop=value where prop starts with a letter. All other lines (e.g., blank lines or lines starting with # are considered as comment lines and are ignored.

Exported functions:

readPropertyFile :: String \rightarrow IO [(String,String)]

Reads a property file and returns the list of properties. Returns empty list if the property file does not exist.

updatePropertyFile :: String \rightarrow String \rightarrow String \rightarrow IO ()

Update a property in a property file or add it, if it is not already there.

A.2.44 Library Read

Library with some functions for reading special tokens. This library is included for backward compatibility. You should use the library ReadNumeric which provides a better interface for these functions.

Exported functions:

readNat :: String \rightarrow Int

Read a natural number in a string. The string might contain leadings blanks and the the number is read up to the first non-digit.

readInt :: String \rightarrow Int

Read a (possibly negative) integer in a string. The string might contain leadings blanks and the integer is read up to the first non-digit.

readHex :: String \rightarrow Int

Read a hexadecimal number in a string. The string might contain leadings blanks and the integer is read up to the first non-hexadecimal digit.

A.2.45 Library ReadNumeric

Library with some functions for reading and converting numeric tokens.

Exported functions:

readInt :: String \rightarrow Maybe (Int,String)

Read a (possibly negative) integer as a first token in a string. The string might contain leadings blanks and the integer is read up to the first non-digit. If the string does not start with an integer token, Nothing is returned, otherwise the result is Just ($v$, $s$), where $v$ is the value of the integer and $s$ is the remaining string without the integer token.
readNat :: String → Maybe (Int, String)

Read a natural number as a first token in a string. The string might contain leadings blanks and the number is read up to the first non-digit. If the string does not start with a natural number token, Nothing is returned, otherwise the result is Just (v, s) where v is the value of the number and s is the remaing string without the number token.

readHex :: String → Maybe (Int, String)

Read a hexadecimal number as a first token in a string. The string might contain leadings blanks and the number is read up to the first non-hexadecimal digit. If the string does not start with a hexadecimal number token, Nothing is returned, otherwise the result is Just (v, s) where v is the value of the number and s is the remaing string without the number token.

readOct :: String → Maybe (Int, String)

Read an octal number as a first token in a string. The string might contain leadings blanks and the number is read up to the first non-octal digit. If the string does not start with an octal number token, Nothing is returned, otherwise the result is Just (v, s) where v is the value of the number and s is the remaing string without the number token.

A.2.46 Library ReadShowTerm

Library for converting ground terms to strings and vice versa.

Exported functions:

showTerm :: a → String

Transforms a ground(!) term into a string representation in standard prefix notation. Thus, showTerm suspends until its argument is ground. This function is similar to the prelude function show but can read the string back with readUnqualifiedTerm (provided that the constructor names are unique without the module qualifier).

showQTerm :: a → String

Transforms a ground(!) term into a string representation in standard prefix notation. Thus, showTerm suspends until its argument is ground. Note that this function differs from the prelude function show since it prefixes constructors with their module name in order to read them back with readQTerm.

readsUnqualifiedTerm :: [String] → String → [(a, String)]

Transform a string containing a term in standard prefix notation without module qualifiers into the corresponding data term. The first argument is a non-empty list of module qualifiers that are tried to prefix the constructor in the string in order to get
the qualified constructors (that must be defined in the current program!). In case of a successful parse, the result is a one element list containing a pair of the data term and the remaining unparsed string.

readUnqualifiedTerm :: [String] → String → a

Transforms a string containing a term in standard prefix notation without module qualifiers into the corresponding data term. The first argument is a non-empty list of module qualifiers that are tried to prefix the constructor in the string in order to get the qualified constructors (that must be defined in the current program!).

Example: readUnqualifiedTerm ["Prelude"] "Just 3" evaluates to (Just 3)

readsTerm :: String → [(a,String)]

For backward compatibility. Should not be used since their use can be problematic in case of constructors with identical names in different modules.

readTerm :: String → a

For backward compatibility. Should not be used since their use can be problematic in case of constructors with identical names in different modules.

readsQTerm :: String → [(a,String)]

Transforms a string containing a term in standard prefix notation with qualified constructor names into the corresponding data term. In case of a successful parse, the result is a one element list containing a pair of the data term and the remaining unparsed string.

readQTerm :: String → a

Transforms a string containing a term in standard prefix notation with qualified constructor names into the corresponding data term.

readQTermFile :: String → IO a

Reads a file containing a string representation of a term in standard prefix notation and returns the corresponding data term.

readQTermListFile :: String → IO [a]

Reads a file containing lines with string representations of terms of the same type and returns the corresponding list of data terms.

writeQTermFile :: String → a → IO ()

Writes a ground term into a file in standard prefix notation.

writeQTermListFile :: String → [a] → IO ()

Writes a list of ground terms into a file. Each term is written into a separate line which might be useful to modify the file with a standard text editor.
This module contains an implementation of set functions. The general idea of set functions is described in:


Intuition: If \( f \) is an \( n \)-ary function, then \( \text{setn} f \) is a set-valued function that collects all non-determinism caused by \( f \) (but not the non-determinism caused by evaluating arguments!) in a set. Thus, \( \text{setn} f \ a1 \ldots \ an \) returns the set of all values of \( f \ b1 \ldots \ bn \) where \( b1,\ldots,\ bn \) are values of the arguments \( a1,\ldots,\ an \) (i.e., the arguments are evaluated "outside" this capsule so that the non-determinism caused by evaluating these arguments is not captured in this capsule but yields several results for \( \text{setn} \ldots \)). Similarly, logical variables occurring in \( a1,\ldots,\ an \) are not bound inside this capsule (but causes a suspension until they are bound). The set of values returned by a set function is represented by an abstract type \textbf{Values} on which several operations are defined in this module. Actually, it is a multiset of values, i.e., duplicates are not removed.

Restrictions:

1. The set is a multiset, i.e., it might contain multiple values.
2. The multiset of values is completely evaluated when demanded. Thus, if it is infinite, its evaluation will not terminate even if only some elements (e.g., for a containment test) are demanded. However, for the emptiness test, at most one value will be computed.
3. The arguments of a set function are strictly evaluated before the set functions itself will be evaluated.

Since this implementation is restricted and prototypical, the interface is not stable and might change.

**Exported types:**

data Values

Abstract type representing multisets of values.

**Exported constructors:**

**Exported functions:**

\texttt{set0 :: a → Values a}

Combinator to transform a 0-ary function into a corresponding set function.

\texttt{set1 :: (a → b) → a → Values b}

Combinator to transform a unary function into a corresponding set function.
set2 :: (a → b → c) → a → b → Values c
    Combinator to transform a binary function into a corresponding set function.

set3 :: (a → b → c → d) → a → b → c → Values d
    Combinator to transform a function of arity 3 into a corresponding set function.

set4 :: (a → b → c → d → e) → a → b → c → d → Values e
    Combinator to transform a function of arity 4 into a corresponding set function.

set5 :: (a → b → c → d → e → f) → a → b → c → d → e → Values f
    Combinator to transform a function of arity 5 into a corresponding set function.

set6 :: (a → b → c → d → e → f → g) → a → b → c → d → e → f → Values g
    Combinator to transform a function of arity 6 into a corresponding set function.

set7 :: (a → b → c → d → e → f → g → h) → a → b → c → d → e → f → g → Values h
    Combinator to transform a function of arity 7 into a corresponding set function.

isEmpty :: Values a → Bool
    Is a multiset of values empty?

notEmpty :: Values a → Bool
    Is a multiset of values not empty?

valueOf :: a → Values a → Bool
    Is some value an element of a multiset of values?

choose :: Values a → (a,Values a)
    Chooses (non-deterministically) some value in a multiset of values and returns
    the chosen value and the remaining multiset of values. Thus, if we consider the
    operation chooseValue by

    chooseValue x = fst (choose x)

    then (set1 chooseValue) is the identity on value sets, i.e., (set1 chooseValue s)
    contains the same elements as the value set s.

chooseValue :: Values a → a
    Chooses (non-deterministically) some value in a multiset of values and returns
    the chosen value. Thus, (set1 chooseValue) is the identity on value sets, i.e.,
    (set1 chooseValue s) contains the same elements as the value set s.
select :: Values a → (a,Values a)

Selects (indeterministically) some value in a multiset of values and returns the selected value and the remaining multiset of values. Thus, select has always at most one value. It fails if the value set is empty.

NOTE: The usage of this operation is only safe (i.e., does not destroy completeness) if all values in the argument set are identical.

selectValue :: Values a → a

Selects (indeterministically) some value in a multiset of values and returns the selected value. Thus, selectValue has always at most one value. It fails if the value set is empty.

NOTE: The usage of this operation is only safe (i.e., does not destroy completeness) if all values in the argument set are identical. It returns a single value even for infinite value sets (in contrast to select or choose).

mapValues :: (a → b) → Values a → Values b

Accumulates all elements of a multiset of values by applying a binary operation. This is similarly to fold on lists, but the binary operation must be commutative so that the result is independent of the order of applying this operation to all elements in the multiset.

foldValues :: (a → a → a) → a → Values a → a

Accumulates all elements of a multiset of values by applying a binary operation. This is similarly to fold on lists, but the binary operation must be commutative so that the result is independent of the order of applying this operation to all elements in the multiset.

minValue :: (a → a → Bool) → Values a → a

Returns the minimal element of a non-empty multiset of values with respect to a given total ordering on the elements.

maxValue :: (a → a → Bool) → Values a → a

Returns the maximal element of a non-empty multiset of value with respect to a given total ordering on the elements.

values2list :: Values a → IO [a]

Puts all elements of a multiset of values in a list. Since the order of the elements in the list might depend on the time of the computation, this operation is an I/O action.

printValues :: Values a → IO ()

Prints all elements of a multiset of values.
sortValues :: Values a → [a]

Transforms a multiset of values into a list sorted by the standard term ordering. As a consequence, the multiset of values is completely evaluated.

sortValuesBy :: (a → a → Bool) → Values a → [a]

Transforms a multiset of values into a list sorted by a given ordering on the values. As a consequence, the multiset of values is completely evaluated. In order to ensure that the result of this operation is independent of the evaluation order, the given ordering must be a total order.

A.2.48 Library Socket

Library to support network programming with sockets. In standard applications, the server side uses the operations \texttt{listenOn} and \texttt{socketAccept} to provide some service on a socket, and the client side uses the operation \texttt{connectToSocket} to request a service.

**Exported types:**

\begin{verbatim}
data Socket

The abstract type of sockets.
\end{verbatim}

**Exported constructors:**

**Exported functions:**

\begin{verbatim}
listenOn :: Int → IO Socket

Creates a server side socket bound to a given port number.

listenOnFresh :: IO (Int,Socket)

Creates a server side socket bound to a free port. The port number and the socket is returned.

socketAccept :: Socket → IO (String,Handle)

Returns a connection of a client to a socket. The connection is returned as a pair consisting of a string identifying the client (the format of this string is implementation-dependent) and a handle to a stream communication with the client. The handle is both readable and writable.

waitForSocketAccept :: Socket → Int → IO (Maybe (String,Handle))

Waits until a connection of a client to a socket is available. If no connection is available within the time limit, it returns Nothing, otherwise the connection is returned as a pair consisting of a string identifying the client (the format of this string is implementation-dependent) and a handle to a stream communication with the client.
\end{verbatim}
sClose :: Socket → IO ()

Closes a server socket.

connectToSocket :: String → Int → IO Handle

Creates a new connection to a Unix socket.

A.2.49 Library System

Library to access parts of the system environment.

Exported functions:

getCPUtilTime :: IO Int

Returns the current cpu time of the process in milliseconds.

getElapsedTime :: IO Int

Returns the current elapsed time of the process in milliseconds. This operation is not supported in KiCS2 (there it always returns 0), but only included for compatibility reasons.

getArgs :: IO [String]

Returns the list of the program’s command line arguments. The program name is not included.

getEnviron :: String → IO String

Returns the value of an environment variable. The empty string is returned for undefined environment variables.

setEnviron :: String → String → IO ()

Set an environment variable to a value. The new value will be passed to subsequent shell commands (see system) and visible to subsequent calls to getEnviron (but it is not visible in the environment of the process that started the program execution).

unsetEnviron :: String → IO ()

Removes an environment variable that has been set by setEnviron.

getHostname :: IO String

Returns the hostname of the machine running this process.

getPID :: IO Int

Returns the process identifier of the current Curry process.

getProgName :: IO String
Returns the name of the current program, i.e., the name of the main module currently executed.

\[ \text{system :: String } \rightarrow \text{ IO Int} \]

Executes a shell command and return with the exit code of the command. An exit status of zero means successful execution.

\[ \text{exitWith :: Int } \rightarrow \text{ IO a} \]

Terminates the execution of the current Curry program and returns the exit code given by the argument. An exit code of zero means successful execution.

\[ \text{sleep :: Int } \rightarrow \text{ IO ()} \]

The evaluation of the action (sleep n) puts the Curry process asleep for n seconds.

\[ \text{isPosix :: Bool} \]

Is the underlying operating system a POSIX system (unix, MacOS)?

\[ \text{isWindows :: Bool} \]

Is the underlying operating system a Windows system?

### A.2.50 Library Time

Library for handling date and time information.

**Exported types:**

\[ \text{data ClockTime} \]

ClockTime represents a clock time in some internal representation.

**Exported constructors:**

\[ \text{data CalendarTime} \]

A calendar time is presented in the following form: (CalendarTime year month day hour minute second timezone) where timezone is an integer representing the timezone as a difference to UTC time in seconds.

**Exported constructors:**

- \[ \text{CalendarTime :: Int } \rightarrow \text{ Int } \rightarrow \text{ Int } \rightarrow \text{ Int } \rightarrow \text{ Int } \rightarrow \text{ Int } \rightarrow \text{ Int } \rightarrow \text{ CalendarTime} \]
Exported functions:

ctYear :: CalendarTime → Int

The year of a calendar time.

ctMonth :: CalendarTime → Int

The month of a calendar time.

ctDay :: CalendarTime → Int

The day of a calendar time.

ctHour :: CalendarTime → Int

The hour of a calendar time.

ctMin :: CalendarTime → Int

The minute of a calendar time.

ctSec :: CalendarTime → Int

The second of a calendar time.

ctTZ :: CalendarTime → Int

The time zone of a calendar time. The value of the time zone is the difference to UTC time in seconds.

getchTime :: IO ClockTime

Returns the current clock time.

getLocalTime :: IO CalendarTime

Returns the local calendar time.

clockTimeToInt :: ClockTime → Int

Transforms a clock time into a unique integer. It is ensured that clock times that differ in at least one second are mapped into different integers.

toCalendarTime :: ClockTime → IO CalendarTime

Transforms a clock time into a calendar time according to the local time (if possible). Since the result depends on the local environment, it is an I/O operation.

toUTCTime :: ClockTime → CalendarTime

Transforms a clock time into a standard UTC calendar time. Thus, this operation is independent on the local time.

toClockTime :: CalendarTime → ClockTime
Transforms a calendar time (interpreted as UTC time) into a clock time.

`calendarTimeToString :: CalendarTime → String`

Transforms a calendar time into a readable form.

`toDayString :: CalendarTime → String`

Transforms a calendar time into a string containing the day, e.g., "September 23, 2006".

`toTimeString :: CalendarTime → String`

Transforms a calendar time into a string containing the time.

`addSeconds :: Int → ClockTime → ClockTime`

Adds seconds to a given time.

`addMinutes :: Int → ClockTime → ClockTime`

Adds minutes to a given time.

`addHours :: Int → ClockTime → ClockTime`

Adds hours to a given time.

`addDays :: Int → ClockTime → ClockTime`

Adds days to a given time.

`addMonths :: Int → ClockTime → ClockTime`

Adds months to a given time.

`addYears :: Int → ClockTime → ClockTime`

Adds years to a given time.

`daysOfMonth :: Int → Int → Int`

Gets the days of a month in a year.

`validDate :: Int → Int → Int → Bool`

Is a date consisting of year/month/day valid?

`compareDate :: CalendarTime → CalendarTime → Ordering`

Compares two dates (don’t use it, just for backward compatibility!).

`compareCalendarTime :: CalendarTime → CalendarTime → Ordering`

Compares two calendar times.

`compareClockTime :: ClockTime → ClockTime → Ordering`

Compares two clock times.
A.2.51 Library Unsafe

Library containing unsafe operations. These operations should be carefully used (e.g., for testing or debugging). These operations should not be used in application programs!

Exported functions:

unsafePerformIO :: IO a → a

Performs and hides an I/O action in a computation (use with care!).

trace :: String → a → a

Prints the first argument as a side effect and behaves as identity on the second argument.

spawnConstraint :: Success → a → a

Spawns a constraint and returns the second argument. This function can be considered as defined by "spawnConstraint c x | c = x". However, the evaluation of the constraint and the right-hand side are performed concurrently, i.e., a suspension of the constraint does not imply a blocking of the right-hand side and the right-hand side might be evaluated before the constraint is successfully solved. Thus, a computation might return a result even if some of the spawned constraints are suspended (use the PAKCS/Curry2Prolog option "+suspend" to show such suspended goals).

isVar :: a → Bool

Tests whether the first argument evaluates to a currently unbound variable (use with care!).

identicalVar :: a → a → Bool

Tests whether both arguments evaluate to the identical currently unbound variable (use with care!). For instance, identicalVar (id x) (fst (x,1)) evaluates to True whereas identicalVar x y and let x=1 in identicalVar x x evaluate to False.

isGround :: a → Bool

Tests whether the argument evaluates to a ground value (use with care!).

compareAnyTerm :: a → a → Ordering

Comparison of any data terms, possibly containing variables. Data constructors are compared in the order of their definition in the datatype declarations and recursively in the arguments. Variables are compared in some internal order.

showAnyTerm :: a → String

Transforms the normal form of a term into a string representation in standard prefix notation. Thus, showAnyTerm evaluates its argument to normal form. This function is similar to the function ReadShowTerm.showTerm but it also transforms logic variables into a string representation that can be read back by Unsafe.read(s)AnyUnqualifiedTerm. Thus, the result depends on the evaluation and binding status of logic variables so that it should be used with care!
showAnyQTerm :: a → String

Transforms the normal form of a term into a string representation in standard prefix notation. Thus, showAnyQTerm evaluates its argument to normal form. This function is similar to the function ReadShowTerm.showQTerm but it also transforms logic variables into a string representation that can be read back by Unsafe.read(s)AnyQTerm. Thus, the result depends on the evaluation and binding status of logic variables so that it should be used with care!

readsAnyUnqualifiedTerm :: [String] → String → [(a,String)]

Transform a string containing a term in standard prefix notation without module qualifiers into the corresponding data term. The string might contain logical variable encodings produced by showAnyTerm. In case of a successful parse, the result is a one element list containing a pair of the data term and the remaining unparsed string.

readAnyUnqualifiedTerm :: [String] → String → a

Transforms a string containing a term in standard prefix notation without module qualifiers into the corresponding data term. The string might contain logical variable encodings produced by showAnyTerm.

readsAnyQTerm :: String → [(a,String)]

Transforms a string containing a term in standard prefix notation with qualified constructor names into the corresponding data term. The string might contain logical variable encodings produced by showAnyQTerm. In case of a successful parse, the result is a one element list containing a pair of the data term and the remaining unparsed string.

readAnyQTerm :: String → a

Transforms a string containing a term in standard prefix notation with qualified constructor names into the corresponding data term. The string might contain logical variable encodings produced by showAnyQTerm.

showAnyExpression :: a → String

Transforms any expression (even not in normal form) into a string representation in standard prefix notation without module qualifiers. The result depends on the evaluation and binding status of logic variables so that it should be used with care!

showAnyQExpression :: a → String

Transforms any expression (even not in normal form) into a string representation in standard prefix notation with module qualifiers. The result depends on the evaluation and binding status of logic variables so that it should be used with care!

readsAnyQExpression :: String → [(a,String)]
Transforms a string containing an expression in standard prefix notation with qualified constructor names into the corresponding expression. The string might contain logical variable and defined function encodings produced by showAnyQExpression. In case of a successful parse, the result is a one element list containing a pair of the expression and the remaining unparsed string.

\[ \text{readAnyQExpression} :: \text{String} \rightarrow a \]

Transforms a string containing an expression in standard prefix notation with qualified constructor names into the corresponding expression. The string might contain logical variable and defined function encodings produced by showAnyQExpression.

### A.3 Data Structures and Algorithms

#### A.3.1 Library Array

Implementation of Arrays with Braun Trees. Conceptually, Braun trees are always infinite. Consequently, there is no test on emptiness.

**Exported types:**

data Array

**Exported constructors:**

**Exported functions:**

- `emptyErrorArray :: Array a`  
  Creates an empty array which generates errors for non-initialized indexes.

- `emptyDefaultArray :: (Int \rightarrow a) \rightarrow Array a`  
  Creates an empty array, call given function for non-initialized indexes.

- `(//) :: Array a \rightarrow [(Int,a)] \rightarrow Array a`  
  Inserts a list of entries into an array.

- `update :: Array a \rightarrow Int \rightarrow a \rightarrow Array a`  
  Inserts a new entry into an array.

- `applyAt :: Array a \rightarrow Int \rightarrow (a \rightarrow a) \rightarrow Array a`  
  Applies a function to an element.

- `(!) :: Array a \rightarrow Int \rightarrow a`  
  Yields the value at a given position.
listToDefaultArray :: (Int → a) → [a] → Array a

Creates a default array from a list of entries.

listToErrorArray :: [a] → Array a

Creates an error array from a list of entries.

combine :: (a → b → c) → Array a → Array b → Array c

combine two arbitrary arrays

combineSimilar :: (a → a → a) → Array a → Array a → Array a

the combination of two arrays with identical default function and a combinator which
is neutral in the default can be implemented much more efficient

A.3.2 Library Dequeue

An implementation of double-ended queues supporting access at both ends in constant amortized
time.

Exported types:

data Queue

The datatype of a queue.

Exported constructors:

Exported functions:

empty :: Queue a

The empty queue.

cons :: a → Queue a → Queue a

Inserts an element at the front of the queue.

snoc :: a → Queue a → Queue a

Inserts an element at the end of the queue.

isEmpty :: Queue a → Bool

Is the queue empty?

deqLength :: Queue a → Int

Returns the number of elements in the queue.

deqHead :: Queue a → a
The first element of the queue.

\texttt{deqTail :: Queue \( a \) \rightarrow Queue \( a \)}

Removes an element at the front of the queue.

\texttt{deqLast :: Queue \( a \) \rightarrow a}

The last element of the queue.

\texttt{deqInit :: Queue \( a \) \rightarrow Queue \( a \)}

Removes an element at the end of the queue.

\texttt{deqReverse :: Queue \( a \) \rightarrow Queue \( a \)}

Reverses a double ended queue.

\texttt{rotate :: Queue \( a \) \rightarrow Queue \( a \)}

Moves the first element to the end of the queue.

\texttt{matchHead :: Queue \( a \) \rightarrow Maybe (a,Queue \( a \))}

Matches the front of a queue. \( \text{matchHead} \ q \) is equivalent to \( \text{if isEmpty} \ q \ \text{then Nothing else Just} \ (\text{deqHead} \ q, \text{deqTail} \ q) \) but more efficient.

\texttt{matchLast :: Queue \( a \) \rightarrow Maybe (a,Queue \( a \))}

Matches the end of a queue. \( \text{matchLast} \ q \) is equivalent to \( \text{if isEmpty} \ q \ \text{then Nothing else Just} \ (\text{deqLast} \ q,\text{deqInit} \ q) \) but more efficient.

\texttt{listToDeq :: [a] \rightarrow Queue \( a \)}

Transforms a list to a double ended queue.

\texttt{deqToList :: Queue \( a \) \rightarrow [a]}

Transforms a double ended queue to a list.

\textbf{A.3.3 Library FiniteMap}

A finite map is an efficient purely functional data structure to store a mapping from keys to values. In order to store the mapping efficiently, an irreflexive(!) order predicate has to be given, i.e., the order predicate \( \text{le} \) should not satisfy \( \text{le} \ x \ x \) for some key \( x \).

Example: To store a mapping from \texttt{Int -> String}, the finite map needs a Boolean predicate like \(<\). This version was ported from a corresponding Haskell library

\textbf{Exported types:}

\texttt{data FM}

\textit{Exported constructors:}
Exported functions:

\[ \text{emptyFM :: (a \to a \to \text{Bool}) \to FM a b} \]

The empty finite map.

\[ \text{unitFM :: (a \to a \to \text{Bool}) \to a \to b \to FM a b} \]

Construct a finite map with only a single element.

\[ \text{listToFM :: (a \to a \to \text{Bool}) \to [(a,b)] \to FM a b} \]

Builds a finite map from given list of tuples (key,element). For multiple occurrences of key, the last corresponding element of the list is taken.

\[ \text{addToFM :: FM a b \to a \to b \to FM a b} \]

Throws away any previous binding and stores the new one given.

\[ \text{addListToFM :: FM a b \to [(a,b)] \to FM a b} \]

Throws away any previous bindings and stores the new ones given. The items are added starting with the first one in the list.

\[ \text{addToFM_C :: (a \to a \to a) \to FM b a \to a \to b \to FM b a} \]

Instead of throwing away the old binding, addToFM_C combines the new element with the old one.

\[ \text{addListToFM_C :: (a \to a \to a) \to FM b a \to [(b,a)] \to FM b a} \]

Combine with a list of tuples (key,element), cf. addToFM_C

\[ \text{delFromFM :: FM a b \to a \to FM a b} \]

Deletes key from finite map. Deletion doesn’t complain if you try to delete something which isn’t there.

\[ \text{delListFromFM :: FM a b \to [a] \to FM a b} \]

Deletes a list of keys from finite map. Deletion doesn’t complain if you try to delete something which isn’t there.

\[ \text{updFM :: FM a b \to a \to (b \to b) \to FM a b} \]

Applies a function to element bound to given key.

\[ \text{splitFM :: FM a b \to a \to \text{Maybe (FM a b,(a,b))}} \]

Combines delFrom and lookup.

\[ \text{plusFM :: FM a b \to FM a b \to FM a b} \]

Efficiently add key element mappings of two maps into a single one. Bindings in right argument shadow those in the left.
plusFM_C :: (a → a → a) → FM b a → FM b a → FM b a

Efficiently combine key/element mappings of two maps into a single one, cf. addToFM_C

minusFM :: FM a b → FM a b → FM a b

(minusFM a1 a2) deletes from a1 any bindings which are bound in a2

intersectFM :: FM a b → FM a b → FM a b

Filters only those keys that are bound in both of the given maps. The elements will be
taken from the second map.

intersectFM_C :: (a → b → c) → FM d a → FM d b → FM d c

Filters only those keys that are bound in both of the given maps and combines the
elements as in addToFM_C.

foldFM :: (a → b → c → c) → c → FM a b → c

Folds finite map by given function.

mapFM :: (a → b → c) → FM a b → FM a c

Applies a given function on every element in the map.

filterFM :: (a → b → Bool) → FM a b → FM a b

Yields a new finite map with only those key/element pairs matching the given predicate.

sizeFM :: FM a b → Int

How many elements does given map contain?

eqFM :: FM a b → FM a b → Bool

Do two given maps contain the same key/element pairs?

isEmptyFM :: FM a b → Bool

Is the given finite map empty?

elemFM :: a → FM a b → Bool

Does given map contain given key?

lookupFM :: FM a b → a → Maybe b

Retrieves element bound to given key

lookupWithDefaultFM :: FM a b → b → a → b

Retrieves element bound to given key. If the element is not contained in map, return
default value.
keyOrder :: FM a b → a → a → Bool

Retrieves the ordering on which the given finite map is built.

minFM :: FM a b → Maybe (a,b)

Retrieves the smallest key/element pair in the finite map according to the basic key ordering.

maxFM :: FM a b → Maybe (a,b)

Retrieves the greatest key/element pair in the finite map according to the basic key ordering.

fmToList :: FM a b → [(a,b)]

Builds a list of key/element pairs. The list is ordered by the initially given irreflexive order predicate on keys.

keysFM :: FM a b → [a]

Retrieves a list of keys contained in finite map. The list is ordered by the initially given irreflexive order predicate on keys.

elsFSM :: FM a b → [b]

Retrieves a list of elements contained in finite map. The list is ordered by the initially given irreflexive order predicate on keys.

fmToListPreOrder :: FM a b → [(a,b)]

Retrieves list of key/element pairs in preorder of the internal tree. Useful for lists that will be retransformed into a tree or to match any elements regardless of basic order.

fmSortBy :: (a → a → Bool) → [a] → [a]

Sorts a given list by inserting and retrieving from finite map. Duplicates are deleted.

showFM :: FM a b → String

Transforms a finite map into a string. For efficiency reasons, the tree structure is shown which is valid for reading only if one uses the same ordering predicate.

readFM :: (a → a → Bool) → String → FM a b

Transforms a string representation of a finite map into a finite map. One has two provide the same ordering predicate as used in the original finite map.
A.3.4 Library GraphInductive

Library for inductive graphs (port of a Haskell library by Martin Erwig).
In this library, graphs are composed and decomposed in an inductive way.
The key idea is as follows:
A graph is either empty or it consists of node context and a graph $g'$ which are put together by a constructor (:&).
This constructor (:&), however, is not a constructor in the sense of abstract data type, but more basically a defined constructing function.
A context is a node together with the edges to and from this node into the nodes in the graph $g'$.
For examples of how to use this library, cf. the module GraphAlgorithms.

Exported types:

```haskell
type Node = Int

Nodes and edges themselves (in contrast to their labels) are coded as integers.
For both of them, there are variants as labeled, unlabeled and quasi unlabeled (labeled with ()).

Unlabeled node

type LNode a = (Int,a)

Labeled node

type UNode = (Int,())

Quasi-unlabeled node

type Edge = (Int,Int)

Unlabeled edge

type LEdge a = (Int,Int,a)

Labeled edge

type UEdge = (Int,Int,())

Quasi-unlabeled edge

type Context a b = ([Int,a],[b])

The context of a node is the node itself (along with label) and its adjacent nodes. Thus, a context is a quadruple, for node n it is of the form (edges to n, node n, n’s label, edges from n)

type MContext a b = Maybe ([Int,a],[b])

maybe context
```
type Context’ a b = ([[(b,Int)],[a,[(b,Int)]])

context with edges and node label only, without the node identifier itself

type UContext = ([Int],[Int])

Unlabeled context.

type GDecomp a b = (([(b,Int)],Int,a,[(b,Int)]),Graph a b)

A graph decomposition is a context for a node n and the remaining graph without that node.

type Decomp a b = (Maybe ([(b,Int)],Int,a,[(b,Int)]),Graph a b)

a decomposition with a maybe context

type UDecomp a = (Maybe ([Int],[Int]),a)

Unlabeled decomposition.

type Path = [Int]

Unlabeled path

type LPath a = [(Int,a)]

Labeled path

type UPath = [(Int,())]

Quasi-unlabeled path

type UGr = Graph () ()

a graph without any labels

data Graph

The type variables of Graph are nodeLabel and edgeLabel. The internal representation of Graph is hidden.

Exported constructors:

Exported functions:

(:&) :: ([([a,Int]],[Int],b,[(a,Int)])) → Graph b a → Graph b a

(:&) takes a node-context and a Graph and yields a new graph.
The according key idea is detailed at the beginning.
nl is the type of the node labels and el the edge labels.
Note that it is an error to induce a context for a node already contained in the graph.
matchAny :: Graph a b → (((b,Int),Int,a,[(b,Int)]),Graph a b)

decompose a graph into the Context for an arbitrarily-chosen Node and the remaining
Graph.

In order to use graphs as abstract data structures, we also need means to decompose a
graph. This decomposition should work as much like pattern matching as possible. The
normal matching is done by the function matchAny, which takes a graph and yields a
graph decomposition.

According to the main idea, matchAny . (:&) should be an identity.

empty :: Graph a b

An empty Graph.

mkGraph :: [(Int,a)] → [(Int,Int,b)] → Graph a b

Create a Graph from the list of LNodes and LEdges.

buildGr :: [[[a,Int]],Int,b,[(a,Int)]] → Graph b a

Build a Graph from a list of Contexts.

mkUGraph :: [Int] → [(Int,Int)] → Graph () ()

Build a quasi-unlabeled Graph from the list of Nodes and Edges.

insNode :: (Int,a) → Graph a b → Graph a b

Insert a LNode into the Graph.

insEdge :: (Int,Int,a) → Graph b a → Graph b a

Insert a LEdge into the Graph.

delNode :: Int → Graph a b → Graph a b

Remove a Node from the Graph.

delEdge :: (Int,Int) → Graph a b → Graph a b

Remove an Edge from the Graph.

insNodes :: [(Int,a)] → Graph a b → Graph a b

Insert multiple LNodes into the Graph.

insEdges :: [(Int,Int,a)] → Graph b a → Graph b a

Insert multiple LEdges into the Graph.

delNodes :: [Int] → Graph a b → Graph a b

Remove multiple Nodes from the Graph.
delEdges :: [(Int,Int)] → Graph a b → Graph a b

Remove multiple Edges from the Graph.

isEmpty :: Graph a b → Bool

test if the given Graph is empty.

match :: Int → Graph a b → (Maybe [(b,Int)],Int,a,[(b,Int)]),Graph a b)

match is the complement side of (:&), decomposing a Graph into the MContext found for the given node and the remaining Graph.

noNodes :: Graph a b → Int

The number of Nodes in a Graph.

nodeRange :: Graph a b → (Int,Int)

The minimum and maximum Node in a Graph.

context :: Graph a b → Int → ([Int],Int,a,[(b,Int)])

Find the context for the given Node. In contrast to "match", "context" causes an error if the Node is not present in the Graph.

lab :: Graph a b → Int → Maybe a

Find the label for a Node.

neighbors :: Graph a b → Int → [Int]

Find the neighbors for a Node.

suc :: Graph a b → Int → [Int]

Find all Nodes that have a link from the given Node.

pre :: Graph a b → Int → [Int]

Find all Nodes that link to the given Node.

lsuc :: Graph a b → Int → [(Int,b)]

Find all Nodes and their labels, which are linked from the given Node.

lpre :: Graph a b → Int → [(Int,b)]

Find all Nodes that link to the given Node and the label of each link.

out :: Graph a b → Int → [(Int,Int,b)]

Find all outward-bound LEdges for the given Node.

inn :: Graph a b → Int → [(Int,Int,b)]
Find all inward-bound LEdges for the given Node.

\text{outdeg :: Graph a b \to Int \to Int}

The outward-bound degree of the Node.

\text{indeg :: Graph a b \to Int \to Int}

The inward-bound degree of the Node.

\text{deg :: Graph a b \to Int \to Int}

The degree of the Node.

\text{gelem :: Int \to Graph a b \to Bool}

True if the Node is present in the Graph.

\text{equal :: Graph a b \to Graph a b \to Bool}

graph equality

\text{node' :: \{[(a,Int)],Int,b,[(a,Int)]\} \to Int}

The Node in a Context.

\text{lab' :: \{[(a,Int)],Int,b,[(a,Int)]\} \to b}

The label in a Context.

\text{labNode' :: \{[(a,Int)],Int,b,[(a,Int)]\} \to (Int,b)}

The LNode from a Context.

\text{neighbors' :: \{[(a,Int)],Int,b,[(a,Int)]\} \to [Int]}

All Nodes linked to or from in a Context.

\text{suc' :: \{[(a,Int)],Int,b,[(a,Int)]\} \to [Int]}

All Nodes linked to in a Context.

\text{pre' :: \{[(a,Int)],Int,b,[(a,Int)]\} \to [Int]}

All Nodes linked from in a Context.

\text{lpre' :: \{[(a,Int)],Int,b,[(a,Int)]\} \to [(Int,a)]}

All Nodes linked from in a Context, and the label of the links.

\text{lSuc' :: \{[(a,Int)],Int,b,[(a,Int)]\} \to [(Int,a)]}

All Nodes linked from in a Context, and the label of the links.

\text{out' :: \{[(a,Int)],Int,b,[(a,Int)]\} \to [(Int,Int,a)]}
All outward-directed LEdges in a Context.

\( \text{inn'} :: \{(a,\text{Int})\}, \text{Int}, b, \{(a,\text{Int})\} \rightarrow \{(\text{Int},\text{Int},a)\} \)

All inward-directed LEdges in a Context.

\( \text{outdeg'} :: \{(a,\text{Int})\}, \text{Int}, b, \{(a,\text{Int})\} \rightarrow \text{Int} \)

The outward degree of a Context.

\( \text{indeg'} :: \{(a,\text{Int})\}, \text{Int}, b, \{(a,\text{Int})\} \rightarrow \text{Int} \)

The inward degree of a Context.

\( \text{deg'} :: \{(a,\text{Int})\}, \text{Int}, b, \{(a,\text{Int})\} \rightarrow \text{Int} \)

The degree of a Context.

\( \text{labNodes} :: \text{Graph} \ a \ b \rightarrow \{(\text{Int},a)\} \)

A list of all LNodes in the Graph.

\( \text{labEdges} :: \text{Graph} \ a \ b \rightarrow \{(\text{Int},\text{Int},b)\} \)

A list of all LEdges in the Graph.

\( \text{nodes} :: \text{Graph} \ a \ b \rightarrow \text{[Int]} \)

List all Nodes in the Graph.

\( \text{edges} :: \text{Graph} \ a \ b \rightarrow \{(\text{Int},\text{Int})\} \)

List all Edges in the Graph.

\( \text{newNodes} :: \text{Int} \rightarrow \text{Graph} \ a \ b \rightarrow \text{[Int]} \)

List N available Nodes, ie Nodes that are not used in the Graph.

\( \text{ufold} :: \{(\{a,\text{Int}\},\text{Int},b,\{(a,\text{Int})\}\} \rightarrow \text{c} \rightarrow \text{c} \rightarrow \text{c} \rightarrow \text{Graph} \ b \ a \rightarrow \text{c} \)

Fold a function over the graph.

\( \text{gmap} :: \{(\{a,\text{Int}\},\text{Int},b,\{(a,\text{Int})\}\} \rightarrow \{(\{c,\text{Int}\},\text{Int},d,\{(c,\text{Int})\}\}\} \rightarrow \text{Graph} \ b \ a \rightarrow \text{Graph} \ d \ c \)

Map a function over the graph.

\( \text{nmap} :: (a \rightarrow b) \rightarrow \text{Graph} \ a \ c \rightarrow \text{Graph} \ b \ c \)

Map a function over the Node labels in a graph.

\( \text{emap} :: (a \rightarrow b) \rightarrow \text{Graph} \ c \ a \rightarrow \text{Graph} \ c \ b \)

Map a function over the Edge labels in a graph.

\( \text{labUEdges} :: [(a,b)] \rightarrow [(a,b,())] \)

add label () to list of edges (node,node)

\( \text{labUNodes} :: [a] \rightarrow [(a,())] \)

add label () to list of nodes

\( \text{showGraph} :: \text{Graph} \ a \ b \rightarrow \text{String} \)

Represent Graph as String
A.3.5 Library Random

Library for pseudo-random number generation in Curry.
This library provides operations for generating pseudo-random number sequences. For any given
seed, the sequences generated by the operations in this module should be identical to the sequences
generated by the java.util.Random package.
The algorithm is a linear congruential pseudo-random number generator described in Donald E.

Exported functions:

nextInt :: Int → [Int]
  Returns a sequence of pseudorandom, uniformly distributed 32-bits integer values. All $2^{32}$ possible integer values are produced with (approximately) equal probability.

nextIntRange :: Int → Int → [Int]
  Returns a pseudorandom, uniformly distributed sequence of values between 0 (inclusive) and the specified value (exclusive). Each value is a 32-bits positive integer. All $n$ possible values are produced with (approximately) equal probability.

nextBoolean :: Int → [Bool]
  Returns a pseudorandom, uniformly distributed sequence of boolean values. The values True and False are produced with (approximately) equal probability.

getRandomSeed :: IO Int
  Returns a time-dependent integer number as a seed for really random numbers. Should only be used as a seed for pseudorandom number sequence and not as a random number since the precision is limited to milliseconds

A.3.6 Library RedBlackTree

Library with an implementation of red-black trees:
Serves as the base for both TableRBT and SetRBT All the operations on trees are generic, i.e.,
one has to provide two explicit order predicates ("lessThan" and "eq"below) on elements.

Exported types:

data RedBlackTree
  A red-black tree consists of a tree structure and three order predicates. These predicates
genralize the red black tree. They define 1) equality when inserting into the tree
eg for a set eqInsert is (==), for a multiset it is (→ False) for a lookUp-table it is ((==) . fst) 2) equality for looking up values eg for a set eqLookUp is (==), for a multiset it is (==) for a lookUp-table it is ((==) . fst) 3) the (less than) relation for the binary search tree

Exported constructors:
Exported functions:

empty :: (a → a → Bool) → (a → a → Bool) → (a → a → Bool) → RedBlackTree a

The three relations are inserted into the structure by function empty. Returns an empty

tree, i.e., an empty red-black tree augmented with the order predicates.

isEmpty :: RedBlackTree a → Bool

Test on emptyness

newTreeLike :: RedBlackTree a → RedBlackTree a

Creates a new empty red black tree from with the same ordering as a give one.

lookup :: a → RedBlackTree a → Maybe a

Returns an element if it is contained in a red-black tree.

update :: a → RedBlackTree a → RedBlackTree a

Updates/inserts an element into a RedBlackTree.

delete :: a → RedBlackTree a → RedBlackTree a

Deletes entry from red black tree.

tree2list :: RedBlackTree a → [a]

Transforms a red-black tree into an ordered list of its elements.

sort :: (a → a → Bool) → [a] → [a]

Generic sort based on insertion into red-black trees. The first argument is the order for
the elements.

setInsertEquivalence :: (a → a → Bool) → RedBlackTree a → RedBlackTree a

For compatibility with old version only

A.3.7 Library SetRBT

Library with an implementation of sets as red-black trees.

All the operations on sets are generic, i.e., one has to provide an explicit order predicate (<)
(less-than) on elements.

Exported types:

type SetRBT a = RedBlackTree a
Exported functions:

emptySetRBT :: (a → a → Bool) → RedBlackTree a

Returns an empty set, i.e., an empty red-black tree augmented with an order predicate.

isEmptySetRBT :: RedBlackTree a → Bool

Test for an empty set.

elemRBT :: a → RedBlackTree a → Bool

Returns true if an element is contained in a (red-black tree) set.

insertRBT :: a → RedBlackTree a → RedBlackTree a

Inserts an element into a set if it is not already there.

insertMultiRBT :: a → RedBlackTree a → RedBlackTree a

Inserts an element into a multiset. Thus, the same element can have several occurrences in the multiset.

deleteRBT :: a → RedBlackTree a → RedBlackTree a

delete an element from a set. Deletes only a single element from a multi set

setRBT2list :: RedBlackTree a → [a]

Transforms a (red-black tree) set into an ordered list of its elements.

unionRBT :: RedBlackTree a → RedBlackTree a → RedBlackTree a

Computes the union of two (red-black tree) sets. This is done by inserting all elements of the first set into the second set.

intersectRBT :: RedBlackTree a → RedBlackTree a → RedBlackTree a

Computes the intersection of two (red-black tree) sets. This is done by inserting all elements of the first set contained in the second set into a new set, which order is taken from the first set.

sortRBT :: (a → a → Bool) → [a] → [a]

Generic sort based on insertion into red-black trees. The first argument is the order for the elements.

A.3.8 Library Sort

A collection of useful functions for sorting and comparing characters, strings, and lists.
Exported functions:

quickSort :: (a → a → Bool) → [a] → [a]

Quicksort.

mergeSort :: (a → a → Bool) → [a] → [a]

Bottom-up mergesort.

leqList :: (a → a → Bool) → [a] → [a] → Bool

Less-or-equal on lists.

cmpList :: (a → a → Ordering) → [a] → [a] → Ordering

Comparison of lists.

leqChar :: Char → Char → Bool

Less-or-equal on characters (deprecated, use Prelude.<=)</code></code>&=/=</code></code>.

cmpChar :: Char → Char → Ordering

Comparison of characters (deprecated, use Prelude.compare).

leqCharIgnoreCase :: Char → Char → Bool

Less-or-equal on characters ignoring case considerations.

leqString :: String → String → Bool

Less-or-equal on strings (deprecated, use Prelude.<=)</code></code>&=/=</code></code>.

cmpString :: String → String → Ordering

Comparison of strings (deprecated, use Prelude.compare).

leqStringIgnoreCase :: String → String → Bool

Less-or-equal on strings ignoring case considerations.

leqLexGerman :: String → String → Bool

Lexicographical ordering on German strings. Thus, upper/lowercase are not distinguished and Umlauts are sorted as vocals.

A.3.9 Library TableRBT

Library with an implementation of tables as red-black trees:

A table is a finite mapping from keys to values. All the operations on tables are generic, i.e., one has to provide an explicit order predicate ("cmp" below) on elements. Each inner node in the red-black tree contains a key-value association.
Exported types:

type TableRBT a b = RedBlackTree (a,b)

Exported functions:

emptyTableRBT :: (a → a → Bool) → RedBlackTree (a,b)

Returns an empty table, i.e., an empty red-black tree.

isEmptyTable :: RedBlackTree (a,b) → Bool

tests whether a given table is empty

lookupRBT :: a → RedBlackTree (a,b) → Maybe b

Looks up an entry in a table.

updateRBT :: a → b → RedBlackTree (a,b) → RedBlackTree (a,b)

Inserts or updates an element in a table.

tableRBT2list :: RedBlackTree (a,b) → [(a,b)]

Transforms the nodes of red-black tree into a list.

deleteRBT :: a → RedBlackTree (a,b) → RedBlackTree (a,b)

A.3.10 Library Traversal

Library to support lightweight generic traversals through tree-structured data. See here\(^{11}\) for a description of the library.

Exported types:

type Traversable a b = a → ([b],[b] → a)

A datatype is Traversable if it defines a function that can decompose a value into a list of children of the same type and recombine new children to a new value of the original type.

\(^{11}\)http://www-ps.informatik.uni-kiel.de/~sebf/projects/traversal.html
Exported functions:

```haskell
noChildren :: a → ([b],[b] → a)
Traversals function for constructors without children.
```

```haskell
children :: (a → ([b],[b] → a)) → a → [b]
Yields the children of a value.
```

```haskell
replaceChildren :: (a → ([b],[b] → a)) → a → [b] → a
Replaces the children of a value.
```

```haskell
mapChildren :: (a → ([b],[b] → a)) → (b → b) → a → a
Applies the given function to each child of a value.
```

```haskell
family :: (a → ([a],[a] → a)) → a → [a]
Computes a list of the given value, its children, those children, etc.
```

```haskell
childFamilies :: (a → ([b],[b] → a)) → (b → ([b],[b] → b)) → a → [b]
Computes a list of family members of the children of a value. The value and its children
 can have different types.
```

```haskell
mapFamily :: (a → ([a],[a] → a)) → (a → a) → a → a
Applies the given function to each member of the family of a value. Proceeds bottom-up.
```

```haskell
mapChildFamilies :: (a → ([b],[b] → a)) → (b → ([b],[b] → b)) → (b → b) → a → a
Applies the given function to each member of the families of the children of a value. The value and its children
 can have different types. Proceeds bottom-up.
```

```haskell
evalFamily :: (a → ([a],[a] → a)) → (a → Maybe a) → a → a
Applies the given function to each member of the family of a value as long as possible.
On each member of the family of the result the given function will yield Nothing.
Proceeds bottom-up.
```

```haskell
evalChildFamilies :: (a → ([b],[b] → a)) → (b → ([b],[b] → b)) → (b → Maybe b) → a → a
Applies the given function to each member of the families of the children of a value as
 long as possible. Similar to evalFamily.
```

```haskell
fold :: (a → ([a],[a] → a)) → (a → [b] → b) → a → b
Implements a traversal similar to a fold with possible default cases.
```
foldChildren :: (a → ([b],[b] → a)) → (b → ([b],[b] → b)) → (a → [c] → d) → (b → [c] → c) → a → d

Fold the children and combine the results.

replaceChildrenIO :: (a → ([b],[b] → a)) → a → IO [b] → IO a

IO version of replaceChildren

mapChildrenIO :: (a → ([b],[b] → a)) → (b → IO b) → a → IO a

IO version of mapChildren

mapFamilyIO :: (a → ([a],[a] → a)) → (a → IO a) → a → IO a

IO version of mapFamily

mapChildFamiliesIO :: (a → ([b],[b] → a)) → (b → ([b],[b] → b)) → (b → IO b) → a → IO a

IO version of mapChildFamilies

evalFamilyIO :: (a → ([a],[a] → a)) → (a → IO (Maybe a)) → a → IO a

IO version of evalFamily

evalChildFamiliesIO :: (a → ([b],[b] → a)) → (b → ([b],[b] → b)) → (b → IO (Maybe b)) → a → IO a

IO version of evalChildFamilies

A.4 Libraries for Web Applications

A.4.1 Library CategorizedHtmlList

This library provides functions to categorize a list of entities into a HTML page with an index access (e.g., "A-Z") to these entities.

Exported functions:

list2CategorizedHtml :: [(a,[HtmlExp])] → [(b,String)] → (a → b → Bool) → [HtmlExp]

General categorization of a list of entries.

The item will occur in every category for which the boolean function categoryFun yields True.

categorizeByItemKey :: [(String,[HtmlExp])] → [HtmlExp]

Categorize a list of entries with respect to the inial keys.

The categories are named as all initial characters of the keys of the items.

stringList2ItemList :: [String] → [(String,[HtmlExp])]

Convert a string list into an key-item list The strings are used as keys and for the simple text layout.
A.4.2 Library HTML

Library for HTML and CGI programming. This paper contains a description of the basic ideas behind this library.

The installation of a cgi script written with this library can be done by the command

\[
\text{makecurrycgi } -m \text{ initialForm } -o \text{ /home/joe/public/html/prog.cgi prog}
\]

where \text{ prog} is the name of the Curry program with the cgi script, \text{/home/joe/public/html/prog.cgi} is the desired location of the compiled cgi script, and \text{ initialForm} is the Curry expression (of type IO HtmlForm) computing the HTML form (where makecurrycgi is a shell script stored in \text{ paks/home/bin}).

Exported types:

\[
\text{type CgiEnv } = \text{ CgiRef } → \text{ String }
\]

The type for representing cgi environments (i.e., mappings from cgi references to the corresponding values of the input elements).

\[
\text{type HtmlHandler } = (\text{ CgiRef } → \text{ String }) → \text{ IO HtmlForm }
\]

The type of event handlers in HTML forms.

\[
\text{data CgiRef }
\]

The (abstract) data type for representing references to input elements in HTML forms.

\textit{Exported constructors:}

\[
\text{data HtmlExp }
\]

The data type for representing HTML expressions.

\textit{Exported constructors:}

- \text{HtmlText} :: \text{String} → \text{HtmlExp}
  \[
  \text{HtmlText } s
  \]
  – a text string without any further structure

- \text{HtmlStruct} :: \text{String} → [(\text{String},\text{String})] → [\text{HtmlExp}] → \text{HtmlExp}
  \[
  \text{HtmlStruct } t\ as\ hs
  \]
  – a structure with a tag, attributes, and HTML expressions inside the structure

- \text{HtmlCRef} :: \text{HtmlExp} → \text{CgiRef} → \text{HtmlExp}
  \[
  \text{HtmlCRef } h\ ref
  \]
  – an input element (described by the first argument) with a cgi reference
• **HtmlEvent**: `HtmlExp -> ((CgiRef -> String) -> IO HtmlForm) -> HtmlExp

  `HtmlEvent h hdlr`

  – an input element (first arg) with an associated event handler (typically, a submit button)

**data HtmlForm**

The data type for representing HTML forms (active web pages) and return values of HTML forms.

*Exported constructors:*

• **HtmlForm**: `String -> [FormParam] -> [HtmlExp] -> HtmlForm`

  `HtmlForm t ps hs`

  – an HTML form with title t, optional parameters (e.g., cookies) ps, and contents hs

• **HtmlAnswer**: `String -> String -> HtmlForm`

  `HtmlAnswer t c`

  – an answer in an arbitrary format where t is the content type (e.g., "text/plain") and c is the contents

**data FormParam**

The possible parameters of an HTML form. The parameters of a cookie (FormCookie) are its name and value and optional parameters (expiration date, domain, path (e.g., the path "/" makes the cookie valid for all documents on the server), security) which are collected in a list.

*Exported constructors:*

• **FormCookie**: `String -> String -> [CookieParam] -> FormParam`

  `FormCookie name value params`

  – a cookie to be sent to the client’s browser

• **FormCSS**: `String -> FormParam`

  `FormCSS s`

  – a URL for a CSS file for this form

• **FormJScript**: `String -> FormParam`

  `FormJScript s`

  – a URL for a Javascript file for this form

• **FormOnSubmit**: `String -> FormParam`

  `FormOnSubmit s`
a JavaScript statement to be executed when the form is submitted (i.e., `<form ... onsubmit="s"/>`)

- **FormTarget :: String → FormParam**
  
  _FormTarget s_

  - a name of a target frame where the output of the script should be represented (should only be used for scripts running in a frame)

- **FormEnc :: String → FormParam**
  
  _FormEnc_

  - the encoding scheme of this form

- **FormMeta :: [(String,String)] → FormParam**
  
  _FormMeta as_

  - meta information (in form of attributes) for this form

- **HeadInclude :: HtmlExp → FormParam**
  
  _HeadInclude he_

  - HTML expression to be included in form header

- **MultipleHandlers :: FormParam**
  
  _MultipleHandlers_

  - indicates that the event handlers of the form can be multiply used (i.e., are not deleted if the form is submitted so that they are still available when going back in the browser; but then there is a higher risk that the web server process might overflow with unused events); the default is a single use of event handlers, i.e., one cannot use the back button in the browser and submit the same form again (which is usually a reasonable behavior to avoid double submissions of data).

- **BodyAttr :: (String,String) → FormParam**
  
  _BodyAttr ps_

  - optional attribute for the body element (more than one occurrence is allowed)

**data CookieParam**

The possible parameters of a cookie.

*Exported constructors:*

- **Cookieexpire :: ClockTime → CookieParam**

- **CookieDomain :: String → CookieParam**
• CookiePath :: String → CookieParam

• CookieSecure :: CookieParam

data HtmlPage

    The data type for representing HTML pages. The constructor arguments are the title, the parameters, and the contents (body) of the web page.

    Exported constructors:

    • HtmlPage :: String → [PageParam] → [HtmlExp] → HtmlPage

data PageParam

    The possible parameters of an HTML page.

    Exported constructors:

    • PageEnc :: String → PageParam
        PageEnc

        – the encoding scheme of this page

    • PageCSS :: String → PageParam
        PageCSS s

        – a URL for a CSS file for this page

    • PageJScript :: String → PageParam
        PageJScript s

        – a URL for a Javascript file for this page

    • PageMeta :: [(String,String)] → PageParam
        PageMeta as

        – meta information (in form of attributes) for this page

    • PageLink :: [(String,String)] → PageParam
        PageLink as

        – link information (in form of attributes) for this page

    • PageBodyAttr :: (String,String) → PageParam
        PageBodyAttr attr

        – optional attribute for the body element of the page (more than one occurrence is allowed)
Exported functions:

defaultEncoding :: String

    The default encoding used in generated web pages.

idOfCgiRef :: CgiRef → String

    Internal identifier of a CgiRef (intended only for internal use in other libraries!).

formEnc :: String → FormParam

    An encoding scheme for a HTML form.

formCSS :: String → FormParam

    A URL for a CSS file for a HTML form.

formMetaInfo :: [(String, String)] → FormParam

    Meta information for a HTML form. The argument is a list of attributes included in
    the meta-tag in the header for this form.

formBodyAttr :: (String, String) → FormParam

    Optional attribute for the body element of the HTML form. More than one occurrence
    is allowed, i.e., all such attributes are collected.

form :: String → [HtmlExp] → HtmlForm

    A basic HTML form for active web pages with the default encoding and a default
    background.

standardForm :: String → [HtmlExp] → HtmlForm

    A standard HTML form for active web pages where the title is included in the body as
    the first header.

cookieForm :: String → [(String, String)] → [HtmlExp] → HtmlForm

    An HTML form with simple cookies. The cookies are sent to the client’s browser
    together with this form.

addCookies :: [(String, String)] → HtmlForm → HtmlForm

    Add simple cookie to HTML form. The cookies are sent to the client’s browser together
    with this form.

answerText :: String → HtmlForm

    A textual result instead of an HTML form as a result for active web pages.

answerEncText :: String → String → HtmlForm
A textual result instead of an HTML form as a result for active web pages where the encoding is given as the first parameter.

\[ \text{addFormParam :: HtmlForm} \rightarrow \text{FormParam} \rightarrow \text{HtmlForm} \]

Adds a parameter to an HTML form.

\[ \text{redirect :: Int} \rightarrow \text{String} \rightarrow \text{HtmlForm} \rightarrow \text{HtmlForm} \]

Adds redirection to given HTML form.

\[ \text{expires :: Int} \rightarrow \text{HtmlForm} \rightarrow \text{HtmlForm} \]

Adds expire time to given HTML form.

\[ \text{addSound :: String} \rightarrow \text{Bool} \rightarrow \text{HtmlForm} \rightarrow \text{HtmlForm} \]

Adds sound to given HTML form. The functions adds two different declarations for sound, one invented by Microsoft for the internet explorer, one introduced for netscape. As neither is an official part of HTML, addsound might not work on all systems and browsers. The greatest chance is by using sound files in MID-format.

\[ \text{pageEnc :: String} \rightarrow \text{PageParam} \]

An encoding scheme for a HTML page.

\[ \text{pageCSS :: String} \rightarrow \text{PageParam} \]

A URL for a CSS file for a HTML page.

\[ \text{pageMetaInfo :: [(String,String)]} \rightarrow \text{PageParam} \]

Meta information for a HTML page. The argument is a list of attributes included in the meta-tag in the header for this page.

\[ \text{pageLinkInfo :: [(String,String)]} \rightarrow \text{PageParam} \]

Link information for a HTML page. The argument is a list of attributes included in the link-tag in the header for this page.

\[ \text{pageBodyAttr :: (String,String)} \rightarrow \text{PageParam} \]

Optional attribute for the body element of the web page. More than one occurrence is allowed, i.e., all such attributes are collected.

\[ \text{page :: String} \rightarrow \text{[HtmlExp]} \rightarrow \text{HtmlPage} \]

A basic HTML web page with the default encoding.

\[ \text{standardPage :: String} \rightarrow \text{[HtmlExp]} \rightarrow \text{HtmlPage} \]

A standard HTML web page where the title is included in the body as the first header.
Adds a parameter to an HTML page.

`htxt :: String → HtmlExp`

Basic text as HTML expression. The text may contain special HTML chars (like `<`, `>`, `&`, `"`) which will be quoted so that they appear as in the parameter string.

`htxts :: [String] → [HtmlExp]`

A list of strings represented as a list of HTML expressions. The strings may contain special HTML chars that will be quoted.

`hempty :: HtmlExp`

An empty HTML expression.

`nbsp :: HtmlExp`

Non breaking Space

`h1 :: [HtmlExp] → HtmlExp`

Header 1

`h2 :: [HtmlExp] → HtmlExp`

Header 2

`h3 :: [HtmlExp] → HtmlExp`

Header 3

`h4 :: [HtmlExp] → HtmlExp`

Header 4

`h5 :: [HtmlExp] → HtmlExp`

Header 5

`par :: [HtmlExp] → HtmlExp`

Paragraph

`emphasize :: [HtmlExp] → HtmlExp`

Emphasize

`strong :: [HtmlExp] → HtmlExp`

Strong (more emphasized) text.

`bold :: [HtmlExp] → HtmlExp`

Boldface
italic :: [HtmlExp] → HtmlExp

Italic

code :: [HtmlExp] → HtmlExp

Program code

center :: [HtmlExp] → HtmlExp

Centered text

blink :: [HtmlExp] → HtmlExp

Blinking text

teletype :: [HtmlExp] → HtmlExp

Teletype font

pre :: [HtmlExp] → HtmExp

Unformatted input, i.e., keep spaces and line breaks and don’t quote special characters.

verbatim :: String → HtmExp

Verbatim (unformatted), special characters (<,>,&,") are quoted.

address :: [HtmlExp] → HtmlExp

Address

href :: String → [HtmlExp] → HtmlExp

Hypertext reference

anchor :: String → [HtmlExp] → HtmlExp

An anchored text with a hypertext reference inside a document.

ulist :: [[HtmlExp]] → HtmlExp

Unordered list

olist :: [[HtmlExp]] → HtmlExp

Ordered list

litem :: [HtmlExp] → HtmlExp

A single list item (usually not explicitly used)

dlist :: ([HtmlExp],[HtmlExp])] → HtmlExp

Description list
table :: \[[[\text{HtmlExp}]]\] → \text{HtmlExp}

Table with a matrix of items where each item is a list of HTML expressions.

headedTable :: \[[[\text{HtmlExp}]]\] → \text{HtmlExp}

Similar to \text{table} but introduces header tags for the first row.

addHeadings :: \text{HtmlExp} → \[[[\text{HtmlExp}]]\] → \text{HtmlExp}

Add a row of items (where each item is a list of HTML expressions) as headings to a table. If the first argument is not a table, the headings are ignored.

hrule :: \text{HtmlExp}

Horizontal rule

breakline :: \text{HtmlExp}

Break a line

image :: \text{String} → \text{String} → \text{HtmlExp}

Image

styleSheet :: \text{String} → \text{HtmlExp}

Defines a style sheet to be used in this HTML document.

style :: \text{String} → \[\text{HtmlExp}\] → \text{HtmlExp}

Provides a style for HTML elements. The style argument is the name of a style class defined in a style definition (see \text{styleSheet}) or in an external style sheet (see form and page parameters \text{FormCSS} and \text{PageCSS}).

textstyle :: \text{String} → \text{String} → \text{HtmlExp}

Provides a style for a basic text. The style argument is the name of a style class defined in an external style sheet.

blockstyle :: \text{String} → \[\text{HtmlExp}\] → \text{HtmlExp}

Provides a style for a block of HTML elements. The style argument is the name of a style class defined in an external style sheet. This element is used (in contrast to "style") for larger blocks of HTML elements since a line break is placed before and after these elements.

inline :: \[\text{HtmlExp}\] → \text{HtmlExp}

Joins a list of HTML elements into a single HTML element. Although this construction has no rendering, it is sometimes useful for programming when several HTML elements must be put together.

block :: \[\text{HtmlExp}\] → \text{HtmlExp}
Joins a list of HTML elements into a block. A line break is placed before and after these elements.

```haskell
button :: String \to ((CgiRef \to String) \to IO HtmlForm) \to HtmlExp
```
Submit button with a label string and an event handler

```haskell
resetbutton :: String \to HtmlExp
```
Reset button with a label string

```haskell
imageButton :: String \to ((CgiRef \to String) \to IO HtmlForm) \to HtmlExp
```
Submit button in form of an imag.

```haskell
textfield :: CgiRef \to String \to HtmlExp
```
Input text field with a reference and an initial contents

```haskell
password :: CgiRef \to HtmlExp
```
Input text field (where the entered text is obscured) with a reference

```haskell
textarea :: CgiRef \to (Int,Int) \to String \to HtmlExp
```
Input text area with a reference, height/width, and initial contents

```haskell
checkbox :: CgiRef \to String \to HtmlExp
```
A checkbox with a reference and a value. The value is returned if checkbox is on, otherwise "" is returned.

```haskell
checkedbox :: CgiRef \to String \to HtmlExp
```
A checkbox that is initially checked with a reference and a value. The value is returned if checkbox is on, otherwise "" is returned.

```haskell
radio_main :: CgiRef \to String \to HtmlExp
```
A main button of a radio (initially "on") with a reference and a value. The value is returned of this button is on. A complete radio button suite always consists of a main button (radiomain) and some further buttons (radiothers) with the same reference. Initially, the main button is selected (or nothing is selected if one uses radiomainoff instead of radio_main). The user can select another button but always at most one button of the radio can be selected. The value corresponding to the selected button is returned in the environment for this radio reference.

```haskell
radio_main_off :: CgiRef \to String \to HtmlExp
```
A main button of a radio (initially "off") with a reference and a value. The value is returned of this button is on.

```haskell
radio_other :: CgiRef \to String \to HtmlExp
```

A further button of a radio (initially "off") with a reference (identical to the main button of this radio) and a value. The value is returned of this button is on.

\[
\text{selection} :: \text{CgiRef} \rightarrow [(\text{String},\text{String})] \rightarrow \text{HtmlExp}
\]

A selection button with a reference and a list of name/value pairs. The names are shown in the selection and the value is returned for the selected name.

\[
\text{selectionInitial} :: \text{CgiRef} \rightarrow [(\text{String},\text{String})] \rightarrow \text{Int} \rightarrow \text{HtmlExp}
\]

A selection button with a reference, a list of name/value pairs, and a preselected item in this list. The names are shown in the selection and the value is returned for the selected name.

\[
\text{multipleSelection} :: \text{CgiRef} \rightarrow [(\text{String},\text{String},\text{Bool})] \rightarrow \text{HtmlExp}
\]

A selection button with a reference and a list of name/value/flag pairs. The names are shown in the selection and the value is returned if the corresponding name is selected. If flag is True, the corresponding name is initially selected. If more than one name has been selected, all values are returned in one string where the values are separated by newline (\n) characters.

\[
\text{hiddenfield} :: \text{String} \rightarrow \text{String} \rightarrow \text{HtmlExp}
\]

A hidden field to pass a value referenced by a fixed name. This function should be used with care since it may cause conflicts with the CGI-based implementation of this library.

\[
\text{htmlQuote} :: \text{String} \rightarrow \text{String}
\]

Quotes special characters (<,>,&"," umlauts) in a string as HTML special characters.

\[
\text{htmlIsoUmlauts} :: \text{String} \rightarrow \text{String}
\]

Translates umlauts in iso-8859-1 encoding into HTML special characters.

\[
\text{addAttr} :: \text{HtmlExp} \rightarrow (\text{String},\text{String}) \rightarrow \text{HtmlExp}
\]

Adds an attribute (name/value pair) to an HTML element.

\[
\text{addAttrs} :: \text{HtmlExp} \rightarrow [(\text{String},\text{String})] \rightarrow \text{HtmlExp}
\]

Adds a list of attributes (name/value pair) to an HTML element.

\[
\text{addClass} :: \text{HtmlExp} \rightarrow \text{String} \rightarrow \text{HtmlExp}
\]

Adds a class attribute to an HTML element.

\[
\text{showHtmlExps} :: [\text{HtmlExp}] \rightarrow \text{String}
\]

Transforms a list of HTML expressions into string representation.

\[
\text{showHtmlExp} :: \text{HtmlExp} \rightarrow \text{String}
\]
Transforms a single HTML expression into string representation.

**showHtmlPage :: HtmlPage → String**

Transforms HTML page into string representation.

**getUrlParameter :: IO String**

Gets the parameter attached to the URL of the script. For instance, if the script is called with URL "http://.../script.cgi?parameter", then "parameter" is returned by this I/O action. Note that an URL parameter should be "URL encoded" to avoid the appearance of characters with a special meaning. Use the functions "urlencoded2string" and "string2urlencoded" to decode and encode such parameters, respectively.

**urlencoded2string :: String → String**

Translates urlencoded string into equivalent ASCII string.

**string2urlencoded :: String → String**

Translates arbitrary strings into equivalent urlencoded string.

**getCookies :: IO [(String,String)]**

Gets the cookies sent from the browser for the current CGI script. The cookies are represented in the form of name/value pairs since no other components are important here.

**coordinates :: (CgiRef → String) → Maybe (Int,Int)**

For image buttons: retrieve the coordinates where the user clicked within the image.

**runFormServerWithKey :: String → String → IO HtmlForm → IO ()**

The server implementing an HTML form (possibly containing input fields). It receives a message containing the environment of the client’s web browser, translates the HTML form w.r.t. this environment into a string representation of the complete HTML document and sends the string representation back to the client’s browser by binding the corresponding message argument.

**runFormServerWithKeyAndFormParams :: String → String → [FormParam] → IO HtmlForm → IO ()**

The server implementing an HTML form (possibly containing input fields). It receives a message containing the environment of the client’s web browser, translates the HTML form w.r.t. this environment into a string representation of the complete HTML document and sends the string representation back to the client’s browser by binding the corresponding message argument.

**showLatexExps :: [HtmlExp] → String**

Transforms HTML expressions into LaTeX string representation.
showLatexExp :: HtmlExp → String

Transforms an HTML expression into LaTeX string representation.

htmlSpecialChars2tex :: String → String

Convert special HTML characters into their LaTeX representation, if necessary.

showLatexDoc :: [HtmlExp] → String

Transforms HTML expressions into a string representation of a complete LaTeX document.

showLatexDocWithPackages :: [HtmlExp] → [String] → String

Transforms HTML expressions into a string representation of a complete LaTeX document. The variable "packages" holds the packages to add to the latex document e.g. "ngerman"

showLatexDocs :: [[HtmlExp]] → String

Transforms a list of HTML expressions into a string representation of a complete LaTeX document where each list entry appears on a separate page.

showLatexDocsWithPackages :: [[HtmlExp]] → [String] → String

Transforms a list of HTML expressions into a string representation of a complete LaTeX document where each list entry appears on a separate page. The variable "packages" holds the packages to add to the latex document (e.g., "ngerman")

germanLatexDoc :: [HtmlExp] → String

show german latex document

intForm :: IO HtmlForm → IO ()

Execute an HTML form in "interactive" mode.

intFormMain :: String → String → String → String → Bool → String → IO HtmlForm → IO ()

Execute an HTML form in "interactive" mode with various parameters.

A.4.3 Library HtmlCgi

Library to support CGI programming in the HTML library. It is only intended as an auxiliary library to implement dynamic web pages according to the HTML library. It contains a simple script that is installed for a dynamic web page and which sends the user input to the real application server implementing the application.
Exported types:

data CgiServerMsg

The messages to communicate between the cgi script and the server program. CgiSubmit env cgienv nextpage - pass the environment and show next page, where env are the values of the environment variables of the web script (e.g., QUERYSTRING, REMOTEHOST, REMOTE_ADDR), cgienv are the values in the current form submitted by the client, and nextpage is the answer text to be shown in the next web page

Exported constructors:

• CgiSubmit :: [(String,String)] → [(String,String)] → CgiServerMsg

• GetLoad :: CgiServerMsg
  
  GetLoad
  
  -- get info about the current load of the server process

• SketchStatus :: CgiServerMsg
  
  SketchStatus
  
  -- get a sketch of the status of the server

• SketchHandlers :: CgiServerMsg
  
  SketchHandlers
  
  -- get a sketch of all event handlers of the server

• ShowStatus :: CgiServerMsg
  
  ShowStatus
  
  -- show the status of the server with all event handlers

• CleanServer :: CgiServerMsg
  
  CleanServer
  
  -- clean up the server (with possible termination)

• StopCgiServer :: CgiServerMsg
  
  StopCgiServer
  
  -- stop the server
Exported functions:

readCgiServerMsg :: Handle → IO (Maybe CgiServerMsg)

Reads a line from a handle and check whether it is a syntactically correct cgi server message.

submitForm :: IO ()

runCgiServerCmd :: String → CgiServerMsg → IO ()

Executes a specific command for a cgi server.

noHandlerPage :: String → String → String

cgiServerRegistry :: String

The name of the file to register all cgi servers.

registerCgiServer :: String → String → IO ()

unregisterCgiServer :: String → IO ()

A.4.4 Library HtmlParser

This module contains a very simple parser for HTML documents.

Exported functions:

readHtmlFile :: String → IO [HtmlExp]

Reads a file with HTML text and returns the corresponding HTML expressions.

parseHtmlString :: String → [HtmlExp]

Transforms an HTML string into a list of HTML expressions. If the HTML string is a well structured document, the list of HTML expressions should contain exactly one element.

A.4.5 Library Mail

This library contains functions for sending emails. The implementation might need to be adapted to the local environment.
Exported types:

```haskell
data MailOption

    Options for sending emails.

Exported constructors:

    • CC :: String → MailOption

    CC

        - recipient of a carbon copy

    • BCC :: String → MailOption

    BCC

        - recipient of a blind carbon copy

    • TO :: String → MailOption

    TO

        - recipient of the email
```

Exported functions:

```haskell
sendMail :: String → String → String → String → IO ()

Sends an email via mailx command.

sendMailWithOptions :: String → String → [MailOption] → String → IO ()

Sends an email via mailx command and various options. Note that multiple options are
allowed, e.g., more than one CC option for multiple recipient of carbon copies.

Important note: The implementation of this operation is based on the command "mailx"
and must be adapted according to your local environment!
```

### A.4.6 Library Markdown

Library to translate markdown documents into HTML or LaTeX. The slightly restricted subset of
the markdown syntax recognized by this implementation is documented in this page.

Exported types:

```haskell
type MarkdownDoc = [MarkdownElem]

A markdown document is a list of markdown elements.
```

```haskell
data MarkdownElem

The data type for representing the different elements occurring in a markdown docu-
ment.
```
Exported constructors:

- **Text :: String → MarkdownElem**
  
  `Text s`

  - a simple text in a markdown document

- **Emph :: String → MarkdownElem**
  
  `Emph s`

  - an emphasized text in a markdown document

- **Strong :: String → MarkdownElem**
  
  `Strong s`

  - a strongly emphaszed text in a markdown document

- **Code :: String → MarkdownElem**
  
  `Code s`

  - a code string in a markdown document

- **HRef :: String → String → MarkdownElem**
  
  `HRef s u`

  - a reference to URL u with text s in a markdown document

- **Par :: [MarkdownElem] → MarkdownElem**
  
  `Par md`

  - a paragraph in a markdown document

- **CodeBlock :: String → MarkdownElem**
  
  `CodeBlock s`

  - a code block in a markdown document

- **UList :: [[MarkdownElem]] → MarkdownElem**
  
  `UList mds`

  - an unordered list in a markdown document

- **OList :: [[MarkdownElem]] → MarkdownElem**
  
  `OList mds`

  - an ordered list in a markdown document

- **Quote :: [MarkdownElem] → MarkdownElem**
  
  `Quote md`
- a quoted paragraph in a markdown document

- HRule :: MarkdownElem
  HRule
  - a horizontal rule in a markdown document

- Header :: Int → String → MarkdownElem
  Header l s
  - a level l header with title s in a markdown document

Exported functions:

fromMarkdownText :: String → [MarkdownElem]
  Parse markdown document from its textual representation.

removeEscapes :: String → String
  Remove the backlash of escaped markdown characters in a string.

markdownEscapeChars :: String
  Escape characters supported by markdown.

markdownText2HTML :: String → [HtmlExp]
  Translate a markdown text into a (partial) HTML document.

markdownText2CompleteHTML :: String → String → String
  Translate a markdown text into a complete HTML text that can be viewed as a standalone document by a browser. The first argument is the title of the document.

markdownText2LaTeX :: String → String
  Translate a markdown text into a (partial) \LaTeX{} document. All characters with a special meaning in \LaTeX{}, like dollar or ampersand signs, are quoted.

markdownText2LaTeXWithFormat :: (String → String) → String → String
  Translate a markdown text into a (partial) \LaTeX{} document where the first argument is a function to translate the basic text occurring in markdown elements to a \LaTeX{} string. For instance, one can use a translation operation that supports passing mathematical formulas in \LaTeX{} style instead of quoting all special characters.

markdownText2CompleteLaTeX :: String → String
  Translate a markdown text into a complete \LaTeX{} document that can be formatted as a standalone document.

formatMarkdownInputAsPDF :: IO ()
  Format the standard input (containing markdown text) as PDF.

formatMarkdownFileAsPDF :: String → IO ()
  Format a file containing markdown text as PDF.
A.4.7 Library URL

Library for dealing with URLs (Uniform Resource Locators).

Exported functions:

\[
\text{getContentsOfUrl} :: \text{String} \rightarrow \text{IO String}
\]

Reads the contents of a document located by a URL. This action requires that the program "wget" is in your path, otherwise the implementation must be adapted to the local installation.

A.4.8 Library WUI

A library to support the type-oriented construction of Web User Interfaces (WUIs).

The ideas behind the application and implementation of WUIs are described in a paper that is available via this web page.

Exported types:

\[
\text{type Rendering} = \lbrack\text{HtmlExp}\rbrack \rightarrow \text{HtmlExp}
\]

A rendering is a function that combines the visualization of components of a data structure into some HTML expression.

data WuiHandler

A handler for a WUI is an event handler for HTML forms possibly with some specific code attached (for future extensions).

\text{Exported constructors:}

data WuiSpec

The type of WUI specifications. The first component are parameters specifying the behavior of this WUI type (rendering, error message, and constraints on inputs). The second component is a "show" function returning an HTML expression for the edit fields and a WUI state containing the CgiRefs to extract the values from the edit fields. The third component is "read" function to extract the values from the edit fields for a given cgi environment (returned as (Just v)). If the value is not legal, Nothing is returned. The second component of the result contains an HTML edit expression together with a WUI state to edit the value again.

\text{Exported constructors:}

data WTree

A simple tree structure to demonstrate the construction of WUIs for tree types.

\text{Exported constructors:}

\begin{itemize}
\item \text{WLeaf} :: a \rightarrow \text{WTre} a
\item \text{WNode} :: \lbrack\text{WTre} a\rbrack \rightarrow \text{WTre} a
\end{itemize}
Exported functions:

\[ \text{wuiHandler2button :: String} \rightarrow \text{WuiHandler} \rightarrow \text{HtmlExp} \]

Transform a WUI handler into a submit button with a given label string.

\[ \text{withRendering :: WuiSpec a} \rightarrow \left(\left[\text{HtmlExp}\right] \rightarrow \text{HtmlExp}\right) \rightarrow \text{WuiSpec a} \]

Puts a new rendering function into a WUI specification.

\[ \text{withError :: WuiSpec a} \rightarrow \text{String} \rightarrow \text{WuiSpec a} \]

Puts a new error message into a WUI specification.

\[ \text{withCondition :: WuiSpec a} \rightarrow \left(\text{a} \rightarrow \text{Bool}\right) \rightarrow \text{WuiSpec a} \]

Puts a new condition into a WUI specification.

\[ \text{transformWSpec :: (a} \rightarrow \text{b,b} \rightarrow \text{a}) \rightarrow \text{WuiSpec a} \rightarrow \text{WuiSpec b} \]

Transforms a WUI specification from one type to another.

\[ \text{adaptWSpec :: (a} \rightarrow \text{b)} \rightarrow \text{WuiSpec a} \rightarrow \text{WuiSpec b} \]

Adapt a WUI specification to a new type. For this purpose, the first argument must be a transformation mapping values from the old type to the new type. This function must be bijective and operationally invertible (i.e., the inverse must be computable by narrowing). Otherwise, use \text{transformWSpec}!

\[ \text{wHidden :: WuiSpec a} \]

A hidden widget for a value that is not shown in the WUI. Usually, this is used in components of larger structures, e.g., internal identifiers, data base keys.

\[ \text{wConstant :: (a} \rightarrow \text{HtmlExp)} \rightarrow \text{WuiSpec a} \]

A widget for values that are shown but cannot be modified. The first argument is a mapping of the value into a HTML expression to show this value.

\[ \text{wInt :: WuiSpec Int} \]

A widget for editing integer values.

\[ \text{wString :: WuiSpec String} \]

A widget for editing string values.

\[ \text{wStringSize :: Int} \rightarrow \text{WuiSpec String} \]

A widget for editing string values with a size attribute.

\[ \text{wRequiredString :: WuiSpec String} \]

A widget for editing string values that are required to be non-empty.
**wRequiredStringSize :: Int → WuiSpec String**

A widget with a size attribute for editing string values that are required to be non-empty.

**wTextArea :: (Int,Int) → WuiSpec String**

A widget for editing string values in a text area. The argument specifies the height and width of the text area.

**wSelect :: (a → String) → [a] → WuiSpec a**

A widget to select a value from a given list of values. The current value should be contained in the value list and is preselected. The first argument is a mapping from values into strings to be shown in the selection widget.

**wSelectInt :: [Int] → WuiSpec Int**

A widget to select a value from a given list of integers (provided as the argument). The current value should be contained in the value list and is preselected.

**wSelectBool :: String → String → WuiSpec Bool**

A widget to select a Boolean value via a selection box. The arguments are the strings that are shown for the values True and False in the selection box, respectively.

**wCheckBool :: [HtmlExp] → WuiSpec Bool**

A widget to select a Boolean value via a check box. The first argument are HTML expressions that are shown after the check box. The result is True if the box is checked.

**wMultiCheckSelect :: (a → [HtmlExp]) → [a] → WuiSpec [a]**

A widget to select a list of values from a given list of values via check boxes. The current values should be contained in the value list and are preselected. The first argument is a mapping from values into HTML expressions that are shown for each item after the check box.

**wRadioSelect :: (a → [HtmlExp]) → [a] → WuiSpec a**

A widget to select a value from a given list of values via a radio button. The current value should be contained in the value list and is preselected. The first argument is a mapping from values into HTML expressions that are shown for each item after the radio button.

**wRadioBool :: [HtmlExp] → [HtmlExp] → WuiSpec Bool**

A widget to select a Boolean value via a radio button. The arguments are the lists of HTML expressions that are shown after the True and False radio buttons, respectively.

**wPair :: WuiSpec a → WuiSpec b → WuiSpec (a,b)**

WUI combinator for pairs.
\(w\text{Cons2} :: (a \to b \to c) \to \text{WuiSpec} a \to \text{WuiSpec} b \to \text{WuiSpec} c\)

WUI combinator for constructors of arity 2. The first argument is the binary constructor. The second and third arguments are the WUI specifications for the argument types.

\(w\text{Triple} :: \text{WuiSpec} a \to \text{WuiSpec} b \to \text{WuiSpec} c \to \text{WuiSpec} (a,b,c)\)

WUI combinator for triples.

\(w\text{Cons3} :: (a \to b \to c \to d) \to \text{WuiSpec} a \to \text{WuiSpec} b \to \text{WuiSpec} c \to \text{WuiSpec} d\)

WUI combinator for constructors of arity 3. The first argument is the ternary constructor. The further arguments are the WUI specifications for the argument types.

\(w\text{4Tuple} :: \text{WuiSpec} a \to \text{WuiSpec} b \to \text{WuiSpec} c \to \text{WuiSpec} d \to \text{WuiSpec} (a,b,c,d)\)

WUI combinator for tuples of arity 4.

\(w\text{Cons4} :: (a \to b \to c \to d \to e) \to \text{WuiSpec} a \to \text{WuiSpec} b \to \text{WuiSpec} c \to \text{WuiSpec} d \to \text{WuiSpec} e\)

WUI combinator for constructors of arity 4. The first argument is the ternary constructor. The further arguments are the WUI specifications for the argument types.

\(w\text{5Tuple} :: \text{WuiSpec} a \to \text{WuiSpec} b \to \text{WuiSpec} c \to \text{WuiSpec} d \to \text{WuiSpec} e \to \text{WuiSpec} (a,b,c,d,e)\)

WUI combinator for tuples of arity 5.

\(w\text{Cons5} :: (a \to b \to c \to d \to e \to f) \to \text{WuiSpec} a \to \text{WuiSpec} b \to \text{WuiSpec} c \to \text{WuiSpec} d \to \text{WuiSpec} e \to \text{WuiSpec} f\)

WUI combinator for constructors of arity 5. The first argument is the ternary constructor. The further arguments are the WUI specifications for the argument types.

\(w\text{6Tuple} :: \text{WuiSpec} a \to \text{WuiSpec} b \to \text{WuiSpec} c \to \text{WuiSpec} d \to \text{WuiSpec} e \to \text{WuiSpec} f \to \text{WuiSpec} (a,b,c,d,e,f)\)

WUI combinator for tuples of arity 6.

\(w\text{Cons6} :: (a \to b \to c \to d \to e \to f \to g) \to \text{WuiSpec} a \to \text{WuiSpec} b \to \text{WuiSpec} c \to \text{WuiSpec} d \to \text{WuiSpec} e \to \text{WuiSpec} f \to \text{WuiSpec} g\)

WUI combinator for constructors of arity 6. The first argument is the ternary constructor. The further arguments are the WUI specifications for the argument types.

\(w\text{7Tuple} :: \text{WuiSpec} a \to \text{WuiSpec} b \to \text{WuiSpec} c \to \text{WuiSpec} d \to \text{WuiSpec} e \to \text{WuiSpec} f \to \text{WuiSpec} g \to \text{WuiSpec} (a,b,c,d,e,f,g)\)

WUI combinator for tuples of arity 7.
wCons7 :: (a \to b \to c \to d \to e \to f \to g \to h) \to \text{WuiSpec} a \to \text{WuiSpec} b \to \text{WuiSpec} c \to \text{WuiSpec} d \to \text{WuiSpec} e \to \text{WuiSpec} f \to \text{WuiSpec} g \to \text{WuiSpec} h

WUI combinator for constructors of arity 7. The first argument is the ternary constructor. The further arguments are the WUI specifications for the argument types.

w8Tuple :: \text{WuiSpec} a \to \text{WuiSpec} b \to \text{WuiSpec} c \to \text{WuiSpec} d \to \text{WuiSpec} e \to \text{WuiSpec} f \to \text{WuiSpec} g \to \text{WuiSpec} h \to \text{WuiSpec} (a,b,c,d,e,f,g,h)

WUI combinator for tuples of arity 8.

wCons8 :: (a \to b \to c \to d \to e \to f \to g \to h \to i) \to \text{WuiSpec} a \to \text{WuiSpec} b \to \text{WuiSpec} c \to \text{WuiSpec} d \to \text{WuiSpec} e \to \text{WuiSpec} f \to \text{WuiSpec} g \to \text{WuiSpec} h \to \text{WuiSpec} i

WUI combinator for constructors of arity 8. The first argument is the ternary constructor. The further arguments are the WUI specifications for the argument types.

w9Tuple :: \text{WuiSpec} a \to \text{WuiSpec} b \to \text{WuiSpec} c \to \text{WuiSpec} d \to \text{WuiSpec} e \to \text{WuiSpec} f \to \text{WuiSpec} g \to \text{WuiSpec} h \to \text{WuiSpec} i \to \text{WuiSpec} (a,b,c,d,e,f,g,h,i)

WUI combinator for tuples of arity 9.

wCons9 :: (a \to b \to c \to d \to e \to f \to g \to h \to i \to j) \to \text{WuiSpec} a \to \text{WuiSpec} b \to \text{WuiSpec} c \to \text{WuiSpec} d \to \text{WuiSpec} e \to \text{WuiSpec} f \to \text{WuiSpec} g \to \text{WuiSpec} h \to \text{WuiSpec} i \to \text{WuiSpec} j

WUI combinator for constructors of arity 9. The first argument is the ternary constructor. The further arguments are the WUI specifications for the argument types.

w10Tuple :: \text{WuiSpec} a \to \text{WuiSpec} b \to \text{WuiSpec} c \to \text{WuiSpec} d \to \text{WuiSpec} e \to \text{WuiSpec} f \to \text{WuiSpec} g \to \text{WuiSpec} h \to \text{WuiSpec} i \to \text{WuiSpec} j \to \text{WuiSpec} (a,b,c,d,e,f,g,h,i,j)

WUI combinator for tuples of arity 10.

wCons10 :: (a \to b \to c \to d \to e \to f \to g \to h \to i \to j \to k) \to \text{WuiSpec} a \to \text{WuiSpec} b \to \text{WuiSpec} c \to \text{WuiSpec} d \to \text{WuiSpec} e \to \text{WuiSpec} f \to \text{WuiSpec} g \to \text{WuiSpec} h \to \text{WuiSpec} i \to \text{WuiSpec} j \to \text{WuiSpec} k

WUI combinator for constructors of arity 10. The first argument is the ternary constructor. The further arguments are the WUI specifications for the argument types.

w11Tuple :: \text{WuiSpec} a \to \text{WuiSpec} b \to \text{WuiSpec} c \to \text{WuiSpec} d \to \text{WuiSpec} e \to \text{WuiSpec} f \to \text{WuiSpec} g \to \text{WuiSpec} h \to \text{WuiSpec} i \to \text{WuiSpec} j \to \text{WuiSpec} k \to \text{WuiSpec} (a,b,c,d,e,f,g,h,i,j,k)

WUI combinator for tuples of arity 11.

wCons11 :: (a \to b \to c \to d \to e \to f \to g \to h \to i \to j \to k \to l) \to \text{WuiSpec} a \to \text{WuiSpec} b \to \text{WuiSpec} c \to \text{WuiSpec} d \to \text{WuiSpec} e \to \text{WuiSpec} f \to \text{WuiSpec} g \to \text{WuiSpec} h \to \text{WuiSpec} i \to \text{WuiSpec} j \to \text{WuiSpec} k \to \text{WuiSpec} l
WUI combinator for constructors of arity 11. The first argument is the ternary constructor. The further arguments are the WUI specifications for the argument types.

\[ w_{12}\text{Tuple} : \text{WuiSpec } a \rightarrow \text{WuiSpec } b \rightarrow \text{WuiSpec } c \rightarrow \text{WuiSpec } d \rightarrow \text{WuiSpec } e \rightarrow \text{WuiSpec } f \rightarrow \text{WuiSpec } g \rightarrow \text{WuiSpec } h \rightarrow \text{WuiSpec } i \rightarrow \text{WuiSpec } j \rightarrow \text{WuiSpec } k \rightarrow \text{WuiSpec } l \rightarrow \text{WuiSpec } (a,b,c,d,e,f,g,h,i,j,k,l) \]

WUI combinator for tuples of arity 12.

\[ w_{\text{Cons}12} : (a \rightarrow b \rightarrow c \rightarrow d \rightarrow e \rightarrow f \rightarrow g \rightarrow h \rightarrow i \rightarrow j \rightarrow k \rightarrow l \rightarrow m) \rightarrow \text{WuiSpec } a \rightarrow \text{WuiSpec } b \rightarrow \text{WuiSpec } c \rightarrow \text{WuiSpec } d \rightarrow \text{WuiSpec } e \rightarrow \text{WuiSpec } f \rightarrow \text{WuiSpec } g \rightarrow \text{WuiSpec } h \rightarrow \text{WuiSpec } i \rightarrow \text{WuiSpec } j \rightarrow \text{WuiSpec } k \rightarrow \text{WuiSpec } l \rightarrow \text{WuiSpec } m \]

WUI combinator for constructors of arity 12. The first argument is the ternary constructor. The further arguments are the WUI specifications for the argument types.

\[ w_{\text{JoinTuple}} : \text{WuiSpec } a \rightarrow \text{WuiSpec } b \rightarrow \text{WuiSpec } (a,b) \]

WUI combinator to combine two tuples into a joint tuple. It is similar to \( w\text{Pair} \) but renders both components as a single tuple provided that the components are already rendered as tuples, i.e., by the rendering function \( \text{renderTuple} \). This combinator is useful to define combinators for large tuples.

\[ w\text{List} : \text{WuiSpec } a \rightarrow \text{WuiSpec } [a] \]

WUI combinator for list structures where the list elements are vertically aligned in a table.

\[ w\text{ListWithHeadings} : [\text{String}] \rightarrow \text{WuiSpec } a \rightarrow \text{WuiSpec } [a] \]

Add headings to a standard WUI for list structures:

\[ w\text{HList} : \text{WuiSpec } a \rightarrow \text{WuiSpec } [a] \]

WUI combinator for list structures where the list elements are horizontally aligned in a table.

\[ w\text{Matrix} : \text{WuiSpec } a \rightarrow \text{WuiSpec } [[a]] \]

WUI for matrices, i.e., list of list of elements visualized as a matrix.

\[ w\text{Maybe} : \text{WuiSpec } \text{Bool} \rightarrow \text{WuiSpec } a \rightarrow a \rightarrow \text{WuiSpec } (\text{Maybe } a) \]

WUI for Maybe values. It is constructed from a WUI for Booleans and a WUI for the potential values. Nothing corresponds to a selection of False in the Boolean WUI. The value WUI is shown after the Boolean WUI.

\[ w\text{CheckMaybe} : \text{WuiSpec } a \rightarrow [\text{HtmlExp}] \rightarrow a \rightarrow \text{WuiSpec } (\text{Maybe } a) \]

A WUI for Maybe values where a check box is used to select Just. The value WUI is shown after the check box.
wRadioMaybe :: WuiSpec a → [HtmlExp] → [HtmlExp] → a → WuiSpec (Maybe a)

A WUI for Maybe values where radio buttons are used to switch between Nothing and Just. The value WUI is shown after the radio button WUI.

wEither :: WuiSpec a → WuiSpec b → WuiSpec (Either a b)

WUI for union types. Here we provide only the implementation for Either types since other types with more alternatives can be easily reduced to this case.

wTree :: WuiSpec a → WuiSpec (WTree a)

WUI for tree types. The rendering specifies the rendering of inner nodes. Leaves are shown with their default rendering.

renderTuple :: [HtmlExp] → HtmlExp

Standard rendering of tuples as a table with a single row. Thus, the elements are horizontally aligned.

renderTaggedTuple :: [String] → [HtmlExp] → HtmlExp

Standard rendering of tuples with a tag for each element. Thus, each is preceded by a tag, that is set in bold, and all elements are vertically aligned.

renderList :: [HtmlExp] → HtmlExp

Standard rendering of lists as a table with a row for each item: Thus, the elements are vertically aligned.

mainWUI :: WuiSpec a → a → (a → IO HtmlForm) → IO HtmlForm

Generates an HTML form from a WUI data specification, an initial value and an update form.

wui2html :: WuiSpec a → a → (a → IO HtmlForm) → (HtmlExp,WuiHandler)

Generates HTML editors and a handler from a WUI data specification, an initial value and an update form.

wuiInForm :: WuiSpec a → a → (a → IO HtmlForm) → (HtmlExp → WuiHandler → IO HtmlForm) → IO HtmlForm

Puts a WUI into a HTML form containing "holes" for the WUI and the handler.

wuiWithErrorForm :: WuiSpec a → a → (a → IO HtmlForm) → (HtmlExp → WuiHandler → IO HtmlForm) → (HtmlExp,WuiHandler)

Generates HTML editors and a handler from a WUI data specification, an initial value and an update form. In addition to wui2html, we can provide a skeleton form used to show illegal inputs.
A.4.9 Library WUIjs

A library to support the type-oriented construction of Web User Interfaces (WUIs). The ideas behind the application and implementation of WUIs are described in a paper that is available via this web page. In addition to the original library, this version provides also support for JavaScript.

Exported types:

```haskell
type Rendering = [HtmlExp] → HtmlExp
```

A rendering is a function that combines the visualization of components of a data structure into some HTML expression.

```haskell
data WuiHandler
```

A handler for a WUI is an event handler for HTML forms possibly with some specific JavaScript code attached.

Exported constructors:

```haskell
data WuiSpec
```

The type of WUI specifications. The first component are parameters specifying the behavior of this WUI type (rendering, error message, and constraints on inputs). The second component is a "show" function returning an HTML expression for the edit fields and a WUI state containing the CgiRefs to extract the values from the edit fields. The third component is "read" function to extract the values from the edit fields for a given cgi environment (returned as (Just v)). If the value is not legal, Nothing is returned. The second component of the result contains an HTML edit expression together with a WUI state to edit the value again.

Exported constructors:

```haskell
data WTree
```

A simple tree structure to demonstrate the construction of WUIs for tree types.

Exported constructors:

- `WLeaf :: a → WTree a`
- `WNode :: [WTree a] → WTree a`
Exported functions:

\texttt{wuiHandler2button :: String \rightarrow WuiHandler \rightarrow HtmlExp}

Transform a WUI handler into a submit button with a given label string.

\texttt{withRendering :: WuiSpec a \rightarrow ([HtmlExp] \rightarrow HtmlExp) \rightarrow WuiSpec a}

Puts a new rendering function into a WUI specification.

\texttt{withError :: WuiSpec a \rightarrow String \rightarrow WuiSpec a}

Puts a new error message into a WUI specification.

\texttt{withCondition :: WuiSpec a \rightarrow (a \rightarrow Bool) \rightarrow WuiSpec a}

Puts a new condition into a WUI specification.

\texttt{withConditionJS :: WuiSpec a \rightarrow (a \rightarrow Bool) \rightarrow WuiSpec a}

Puts a new JavaScript implementation of the condition into a WUI specification.

\texttt{withConditionJSName :: WuiSpec a \rightarrow (a \rightarrow Bool, String) \rightarrow WuiSpec a}

Puts a new JavaScript implementation of the condition into a WUI specification.

\texttt{transformWSpec :: (a \rightarrow b, b \rightarrow a) \rightarrow WuiSpec a \rightarrow WuiSpec b}

Transforms a WUI specification from one type to another.

\texttt{adaptWSpec :: (a \rightarrow b) \rightarrow WuiSpec a \rightarrow WuiSpec b}

Adapt a WUI specification to a new type. For this purpose, the first argument must be a transformation mapping values from the old type to the new type. This function must be bijective and operationally invertible (i.e., the inverse must be computable by narrowing). Otherwise, use \texttt{transformWSpec}!

\texttt{wHidden :: WuiSpec a}

A hidden widget for a value that is not shown in the WUI. Usually, this is used in components of larger structures, e.g., internal identifiers, data base keys.

\texttt{wConstant :: (a \rightarrow HtmlExp) \rightarrow WuiSpec a}

A widget for values that are shown but cannot be modified. The first argument is a mapping of the value into a HTML expression to show this value.

\texttt{wInt :: WuiSpec Int}

A widget for editing integer values.

\texttt{wString :: WuiSpec String}

A widget for editing string values.
wStringSize :: Int → WuiSpec String

A widget for editing string values with a size attribute.

wRequiredString :: WuiSpec String

A widget for editing string values that are required to be non-empty.

wRequiredStringSize :: Int → WuiSpec String

A widget with a size attribute for editing string values that are required to be non-empty.

wTextArea :: (Int,Int) → WuiSpec String

A widget for editing string values in a text area. The argument specifies the height and width of the text area.

wSelect :: (a → String) → [a] → WuiSpec a

A widget to select a value from a given list of values. The current value should be contained in the value list and is preselected. The first argument is a mapping from values into strings to be shown in the selection widget.

wSelectInt :: [Int] → WuiSpec Int

A widget to select a value from a given list of integers (provided as the argument). The current value should be contained in the value list and is preselected.

wSelectBool :: String → String → WuiSpec Bool

A widget to select a Boolean value via a selection box. The arguments are the strings that are shown for the values True and False in the selection box, respectively.

wCheckBool :: [HtmlExp] → WuiSpec Bool

A widget to select a Boolean value via a check box. The first argument are HTML expressions that are shown after the check box. The result is True if the box is checked.

wMultiCheckSelect :: (a → [HtmlExp]) → [a] → WuiSpec [a]

A widget to select a list of values from a given list of values via check boxes. The current values should be contained in the value list and are preselected. The first argument is a mapping from values into HTML expressions that are shown for each item after the check box.

wRadioSelect :: (a → [HtmlExp]) → [a] → WuiSpec a

A widget to select a value from a given list of values via a radio button. The current value should be contained in the value list and is preselected. The first argument is a mapping from values into HTML expressions that are shown for each item after the radio button.

wRadioBool :: [HtmlExp] → [HtmlExp] → WuiSpec Bool

202
A widget to select a Boolean value via a radio button. The arguments are the lists of HTML expressions that are shown after the True and False radio buttons, respectively.

\[ \text{wJoinTuple} :: \text{WuiSpec}\ a \rightarrow \text{WuiSpec}\ b \rightarrow \text{WuiSpec}\ (a,b) \]

WUI combinator to combine two tuples into a joint tuple. It is similar to \text{wPair} but renders both components as a single tuple provided that the components are already rendered as tuples, i.e., by the rendering function \text{renderTuple}. This combinator is useful to define combinators for large tuples.

\[ \text{wPair} :: \text{WuiSpec}\ a \rightarrow \text{WuiSpec}\ b \rightarrow \text{WuiSpec}\ (a,b) \]

WUI combinator for pairs.

\[ \text{wCons2} :: (a \rightarrow b \rightarrow c) \rightarrow \text{WuiSpec}\ a \rightarrow \text{WuiSpec}\ b \rightarrow \text{WuiSpec}\ c \]

WUI combinator for constructors of arity 2. The first argument is the binary constructor. The second and third arguments are the WUI specifications for the argument types.

\[ \text{wCons2JS} :: \text{Maybe}\ ([\text{JSExp}] \rightarrow \text{JSExp}) \rightarrow (a \rightarrow b \rightarrow c) \rightarrow \text{WuiSpec}\ a \rightarrow \text{WuiSpec}\ b \rightarrow \text{WuiSpec}\ c \]

\[ \text{wTriple} :: \text{WuiSpec}\ a \rightarrow \text{WuiSpec}\ b \rightarrow \text{WuiSpec}\ c \rightarrow \text{WuiSpec}\ (a,b,c) \]

WUI combinator for triples.

\[ \text{wCons3} :: (a \rightarrow b \rightarrow c \rightarrow d) \rightarrow \text{WuiSpec}\ a \rightarrow \text{WuiSpec}\ b \rightarrow \text{WuiSpec}\ c \rightarrow \text{WuiSpec}\ d \]

WUI combinator for constructors of arity 3. The first argument is the ternary constructor. The further arguments are the WUI specifications for the argument types.

\[ \text{wCons3JS} :: \text{Maybe}\ ([\text{JSExp}] \rightarrow \text{JSExp}) \rightarrow (a \rightarrow b \rightarrow c \rightarrow d) \rightarrow \text{WuiSpec}\ a \rightarrow \text{WuiSpec}\ b \rightarrow \text{WuiSpec}\ c \rightarrow \text{WuiSpec}\ d \]

\[ \text{w4Tuple} :: \text{WuiSpec}\ a \rightarrow \text{WuiSpec}\ b \rightarrow \text{WuiSpec}\ c \rightarrow \text{WuiSpec}\ d \rightarrow \text{WuiSpec}\ (a,b,c,d) \]

WUI combinator for tuples of arity 4.

\[ \text{wCons4} :: (a \rightarrow b \rightarrow c \rightarrow d \rightarrow e) \rightarrow \text{WuiSpec}\ a \rightarrow \text{WuiSpec}\ b \rightarrow \text{WuiSpec}\ c \rightarrow \text{WuiSpec}\ d \rightarrow \text{WuiSpec}\ e \]

WUI combinator for constructors of arity 4. The first argument is the ternary constructor. The further arguments are the WUI specifications for the argument types.

\[ \text{wCons4JS} :: \text{Maybe}\ ([\text{JSExp}] \rightarrow \text{JSExp}) \rightarrow (a \rightarrow b \rightarrow c \rightarrow d \rightarrow e) \rightarrow \text{WuiSpec}\ a \rightarrow \text{WuiSpec}\ b \rightarrow \text{WuiSpec}\ c \rightarrow \text{WuiSpec}\ d \rightarrow \text{WuiSpec}\ e \]
w5Tuple :: WuiSpec a → WuiSpec b → WuiSpec c → WuiSpec d → WuiSpec e → WuiSpec (a,b,c,d,e)

WUI combinator for tuples of arity 5.

wCons5 :: (a → b → c → d → e → f) → WuiSpec a → WuiSpec b → WuiSpec c → WuiSpec d → WuiSpec e → WuiSpec f

WUI combinator for constructors of arity 5. The first argument is the ternary constructor. The further arguments are the WUI specifications for the argument types.

wCons5JS :: Maybe ([JSExp] → JSExp) → (a → b → c → d → e → f) → WuiSpec a → WuiSpec b → WuiSpec c → WuiSpec d → WuiSpec e → WuiSpec f

w6Tuple :: WuiSpec a → WuiSpec b → WuiSpec c → WuiSpec d → WuiSpec e → WuiSpec f → WuiSpec (a,b,c,d,e,f)

WUI combinator for tuples of arity 6.

wCons6 :: (a → b → c → d → e → f → g) → WuiSpec a → WuiSpec b → WuiSpec c → WuiSpec d → WuiSpec e → WuiSpec f → WuiSpec g

WUI combinator for constructors of arity 6. The first argument is the ternary constructor. The further arguments are the WUI specifications for the argument types.

wCons6JS :: Maybe ([JSExp] → JSExp) → (a → b → c → d → e → f → g) → WuiSpec a → WuiSpec b → WuiSpec c → WuiSpec d → WuiSpec e → WuiSpec f → WuiSpec g

w7Tuple :: WuiSpec a → WuiSpec b → WuiSpec c → WuiSpec d → WuiSpec e → WuiSpec f → WuiSpec g → WuiSpec (a,b,c,d,e,f,g)

WUI combinator for tuples of arity 7.

wCons7 :: (a → b → c → d → e → f → g → h) → WuiSpec a → WuiSpec b → WuiSpec c → WuiSpec d → WuiSpec e → WuiSpec f → WuiSpec g → WuiSpec h

WUI combinator for constructors of arity 7. The first argument is the ternary constructor. The further arguments are the WUI specifications for the argument types.

wCons7JS :: Maybe ([JSExp] → JSExp) → (a → b → c → d → e → f → g → h) → WuiSpec a → WuiSpec b → WuiSpec c → WuiSpec d → WuiSpec e → WuiSpec f → WuiSpec g → WuiSpec h

w8Tuple :: WuiSpec a → WuiSpec b → WuiSpec c → WuiSpec d → WuiSpec e → WuiSpec f → WuiSpec g → WuiSpec h → WuiSpec (a,b,c,d,e,f,g,h)
WUI combinator for tuples of arity 8.

\[
wCons8 :: (a \to b \to c \to d \to e \to f \to g \to h \to i) \to WuiSpec a \to WuiSpec b \to WuiSpec c \to WuiSpec d \to WuiSpec e \to WuiSpec f \to WuiSpec g \to WuiSpec h \to WuiSpec i
\]

WUI combinator for constructors of arity 8. The first argument is the ternary constructor. The further arguments are the WUI specifications for the argument types.

\[
wCons8JS :: \text{Maybe} ([\text{JSExp}] \to \text{JSExp}) \to (a \to b \to c \to d \to e \to f \to g \to h \to i) \to WuiSpec a \to WuiSpec b \to WuiSpec c \to WuiSpec d \to WuiSpec e \to WuiSpec f \to WuiSpec g \to WuiSpec h \to WuiSpec i
\]

WUI combinator for tuples of arity 9.

\[
wCons9 :: (a \to b \to c \to d \to e \to f \to g \to h \to i \to j) \to WuiSpec a \to WuiSpec b \to WuiSpec c \to WuiSpec d \to WuiSpec e \to WuiSpec f \to WuiSpec g \to WuiSpec h \to WuiSpec i \to WuiSpec j
\]

WUI combinator for constructors of arity 9. The first argument is the ternary constructor. The further arguments are the WUI specifications for the argument types.

\[
wCons9JS :: \text{Maybe} ([\text{JSExp}] \to \text{JSExp}) \to (a \to b \to c \to d \to e \to f \to g \to h \to i \to j) \to WuiSpec a \to WuiSpec b \to WuiSpec c \to WuiSpec d \to WuiSpec e \to WuiSpec f \to WuiSpec g \to WuiSpec h \to WuiSpec i \to WuiSpec j
\]

WUI combinator for tuples of arity 10.

\[
wCons10 :: (a \to b \to c \to d \to e \to f \to g \to h \to i \to j \to k) \to WuiSpec a \to WuiSpec b \to WuiSpec c \to WuiSpec d \to WuiSpec e \to WuiSpec f \to WuiSpec g \to WuiSpec h \to WuiSpec i \to WuiSpec j \to WuiSpec k
\]

WUI combinator for constructors of arity 10. The first argument is the ternary constructor. The further arguments are the WUI specifications for the argument types.

\[
wCons10JS :: \text{Maybe} ([\text{JSExp}] \to \text{JSExp}) \to (a \to b \to c \to d \to e \to f \to g \to h \to i \to j \to k) \to WuiSpec a \to WuiSpec b \to WuiSpec c \to WuiSpec d \to WuiSpec e \to WuiSpec f \to WuiSpec g \to WuiSpec h \to WuiSpec i \to WuiSpec j \to WuiSpec k
\]
w11Tuple :: WuiSpec a → WuiSpec b → WuiSpec c → WuiSpec d → WuiSpec e → WuiSpec f → WuiSpec g → WuiSpec h → WuiSpec i → WuiSpec j → WuiSpec k → WuiSpec (a,b,c,d,e,f,g,h,i,j,k)

WUI combinator for tuples of arity 11.

wCons11 :: (a → b → c → d → e → f → g → h → i → j → k → l) → WuiSpec a → WuiSpec b → WuiSpec c → WuiSpec d → WuiSpec e → WuiSpec f → WuiSpec g → WuiSpec h → WuiSpec i → WuiSpec j → WuiSpec k → WuiSpec l

WUI combinator for constructors of arity 11. The first argument is the ternary constructor. The further arguments are the WUI specifications for the argument types.

wCons11JS :: Maybe ([JSExp] → JSExp) → (a → b → c → d → e → f → g → h → i → j → k → l) → WuiSpec a → WuiSpec b → WuiSpec c → WuiSpec d → WuiSpec e → WuiSpec f → WuiSpec g → WuiSpec h → WuiSpec i → WuiSpec j → WuiSpec k → WuiSpec l

w12Tuple :: WuiSpec a → WuiSpec b → WuiSpec c → WuiSpec d → WuiSpec e → WuiSpec f → WuiSpec g → WuiSpec h → WuiSpec i → WuiSpec j → WuiSpec k → WuiSpec l → WuiSpec (a,b,c,d,e,f,g,h,i,j,k,l)

WUI combinator for tuples of arity 12.

wCons12 :: (a → b → c → d → e → f → g → h → i → j → k → l → m) → WuiSpec a → WuiSpec b → WuiSpec c → WuiSpec d → WuiSpec e → WuiSpec f → WuiSpec g → WuiSpec h → WuiSpec i → WuiSpec j → WuiSpec k → WuiSpec l → WuiSpec m

WUI combinator for constructors of arity 12. The first argument is the ternary constructor. The further arguments are the WUI specifications for the argument types.

wCons12JS :: Maybe ([JSExp] → JSExp) → (a → b → c → d → e → f → g → h → i → j → k → l → m) → WuiSpec a → WuiSpec b → WuiSpec c → WuiSpec d → WuiSpec e → WuiSpec f → WuiSpec g → WuiSpec h → WuiSpec i → WuiSpec j → WuiSpec k → WuiSpec l → WuiSpec m

wList :: WuiSpec a → WuiSpec [a]

WUI combinator for list structures where the list elements are vertically aligned in a table.

wListWithHeadings :: [String] → WuiSpec a → WuiSpec [a]

Add headings to a standard WUI for list structures:

wHList :: WuiSpec a → WuiSpec [a]
WUI combinator for list structures where the list elements are horizontally aligned in a table.

\[ \text{wMatrix} :: \text{WuiSpec } a \rightarrow \text{WuiSpec } [[a]] \]

WUI for matrices, i.e., list of list of elements visualized as a matrix.

\[ \text{wMaybe} :: \text{WuiSpec } \text{Bool} \rightarrow \text{WuiSpec } a \rightarrow a \rightarrow \text{WuiSpec } \text{(Maybe } a) \]

WUI for Maybe values. It is constructed from a WUI for Booleans and a WUI for the potential values. Nothing corresponds to a selection of False in the Boolean WUI. The value WUI is shown after the Boolean WUI.

\[ \text{wCheckMaybe} :: \text{WuiSpec } a \rightarrow [\text{HtmlExp}] \rightarrow a \rightarrow \text{WuiSpec } \text{(Maybe } a) \]

A WUI for Maybe values where a check box is used to select Just. The value WUI is shown after the check box.

\[ \text{wRadioMaybe} :: \text{WuiSpec } a \rightarrow [\text{HtmlExp}] \rightarrow [\text{HtmlExp}] \rightarrow a \rightarrow \text{WuiSpec } \text{(Maybe } a) \]

A WUI for Maybe values where radio buttons are used to switch between Nothing and Just. The value WUI is shown after the radio button WUI.

\[ \text{wEither} :: \text{WuiSpec } a \rightarrow \text{WuiSpec } b \rightarrow \text{WuiSpec } \text{(Either } a \text{ } b) \]

WUI for union types. Here we provide only the implementation for Either types since other types with more alternatives can be easily reduced to this case.

\[ \text{wTree} :: \text{WuiSpec } a \rightarrow \text{WuiSpec } \text{(WTree } a) \]

WUI for tree types. The rendering specifies the rendering of inner nodes. Leaves are shown with their default rendering.

\[ \text{renderTuple} :: [\text{HtmlExp}] \rightarrow \text{HtmlExp} \]

Standard rendering of tuples as a table with a single row. Thus, the elements are horizontally aligned.

\[ \text{renderTaggedTuple} :: [\text{String}] \rightarrow [\text{HtmlExp}] \rightarrow \text{HtmlExp} \]

Standard rendering of tuples with a tag for each element. Thus, each is preceded by a tag, that is set in bold, and all elements are vertically aligned.

\[ \text{renderList} :: [\text{HtmlExp}] \rightarrow \text{HtmlExp} \]

Standard rendering of lists as a table with a row for each item: Thus, the elements are vertically aligned.

\[ \text{mainWUI} :: \text{WuiSpec } a \rightarrow a \rightarrow (a \rightarrow \text{IO HtmlForm}) \rightarrow \text{IO HtmlForm} \]

Generates an HTML form from a WUI data specification, an initial value and an update form.
wui2html :: WuiSpec a → a → (a → IO HtmlForm) → (HtmlExp,WuiHandler)

Generates HTML editors and a handler from a WUI data specification, an initial value and an update form.

wuiInForm :: WuiSpec a → a → (a → IO HtmlForm) → (HtmlExp → WuiHandler → IO HtmlForm) → IO HtmlForm

Puts a WUI into a HTML form containing "holes" for the WUI and the handler.

wuiWithErrorForm :: WuiSpec a → a → (a → IO HtmlForm) → (HtmlExp → WuiHandler → IO HtmlForm) → (HtmlExp,WuiHandler)

Generates HTML editors and a handler from a WUI data specification, an initial value and an update form. In addition to wui2html, we can provide a skeleton form used to show illegal inputs.

A.4.10 Library XML

Library for processing XML data.
Warning: the structure of this library is not stable and might be changed in the future!

Exported types:

data XmlExp

The data type for representing XML expressions.

Exported constructors:

• XText :: String → XmlExp
  XText
  – a text string (PCDATA)

• XElement :: String → [(String,String)] → XmlExp → XmlExp
  XElement
  – an XML element with tag field, attributes, and a list of XML elements as contents

data Encoding

The data type for encodings used in the XML document.

Exported constructors:

• StandardEnc :: Encoding

• Iso88591Enc :: Encoding
The data type for XML document parameters.

Exported constructors:

- Enc :: Encoding → XmlDocParams
  
  Enc
  
  -- the encoding for a document

- DtdUrl :: String → XmlDocParams
  
  DtdUrl
  
  -- the url of the DTD for a document

Exported functions:

tagOf :: XmlExp → String

  Returns the tag of an XML element (or empty for a textual element).

elemsOf :: XmlExp → [XmlExp]

  Returns the child elements an XML element.

textOf :: [XmlExp] → String

  Extracts the textual contents of a list of XML expressions. Useful auxiliary function
  when transforming XML expressions into other data structures.
  For instance, textOf [XText "xy", XElem "a" [], XText "bc"] == "xy bc"

textOfXml :: [XmlExp] → String

  Included for backward compatibility, better use textOf!

xtxt :: String → XmlExp

  Basic text (maybe containing special XML chars).

xml :: String → [XmlExp] → XmlExp

  XML element without attributes.

writeXmlFile :: String → XmlExp → IO ()

  Writes a file with a given XML document.

writeXmlFileWithParams :: String → [XmlDocParams] → XmlExp → IO ()

  Writes a file with a given XML document and XML parameters.

showXmlDoc :: XmlExp → String

  Show an XML document in indented format as a string.
showXmlDocWithParams :: [XmlDocParams] → XmlExp → String

readXmlFile :: String → IO XmlExp

Reads a file with an XML document and returns the corresponding XML expression.

readUnsafeXmlFile :: String → IO (Maybe XmlExp)

Tries to read a file with an XML document and returns the corresponding XML expression, if possible. If file or parse errors occur, Nothing is returned.

readFileWithXmlDocs :: String → IO [XmlExp]

Reads a file with an arbitrary sequence of XML documents and returns the list of corresponding XML expressions.

parseXmlString :: String → [XmlExp]

Transforms an XML string into a list of XML expressions. If the XML string is a well structured document, the list of XML expressions should contain exactly one element.

updateXmlFile :: (XmlExp → XmlExp) → String → IO ()

An action that updates the contents of an XML file by some transformation on the XML document.

A.4.11 Library XmlConv

Provides type-based combinators to construct XML converters. Arbitrary XML data can be represented as algebraic datatypes and vice versa. See here\(^{12}\) for a description of this library.

Exported types:

type XmlReads a = ((String, String), [XmlExp]) → (a, ((String, String), [XmlExp]))

Type of functions that consume some XML data to compute a result

type XmlShows a = a → ((String, String), [XmlExp]) → ((String, String), [XmlExp])

Type of functions that extend XML data corresponding to a given value

type XElemConv a = XmlConv Repeatable Elem a

Type of converters for XML elements

type XAttrConv a = XmlConv NotRepeatable NoElem a

Type of converters for attributes

type XPrimConv a = XmlConv NotRepeatable NoElem a

\(^{12}\)http://www-ps.informatik.uni-kiel.de/~sebf/projects/xmlconv/
Type of converters for primitive values

```haskell
type XOptConv a = XmlConv NotRepeatable NoElem a
```

Type of converters for optional values

```haskell
type XRepConv a = XmlConv NotRepeatable NoElem a
```

Type of converters for repetitions

Exported functions:

```haskell
xmlReads :: XmlConv a b c → ([String],[XmlExp]) → (c,([String],[XmlExp]))
```

Takes an XML converter and returns a function that consumes XML data and returns
the remaining data along with the result.

```haskell
xmlShows :: XmlConv a b c → ([String],[XmlExp]) → ([String],[XmlExp])
```

Takes an XML converter and returns a function that extends XML data with the
representation of a given value.

```haskell
xmlRead :: XmlConv a Elem b → XmlExp → b
```

Takes an XML converter and an XML expression and returns a corresponding Curry
value.

```haskell
xmlShow :: XmlConv a Elem b → b → XmlExp
```

Takes an XML converter and a value and returns a corresponding XML expression.

```haskell
int :: XmlConv NotRepeatable NoElem Int
```

Creates an XML converter for integer values. Integer values must not be used in repe-
titions and do not represent XML elements.

```haskell
float :: XmlConv NotRepeatable NoElem Float
```

Creates an XML converter for float values. Float values must not be used in repetitions
and do not represent XML elements.

```haskell
char :: XmlConv NotRepeatable NoElem Char
```

Creates an XML converter for character values. Character values must not be used in repetitions
and do not represent XML elements.

```haskell
string :: XmlConv NotRepeatable NoElem String
```

Creates an XML converter for string values. String values must not be used in repetitions
and do not represent XML elements.
(!) :: XmlConv a b c → XmlConv a b c → XmlConv a b c

Parallel composition of XML converters.

element :: String → XmlConv a b c → XmlConv Repeatable Elem c

Takes an arbitrary XML converter and returns a converter representing an XML element that contains the corresponding data. XML elements may be used in repetitions.

empty :: a → XmlConv NotRepeatable NoElem a

Takes a value and returns an XML converter for this value which is not represented as XML data. Empty XML data must not be used in repetitions and does not represent an XML element.

attr :: String → (String → a,a → String) → XmlConv NotRepeatable NoElem a

Takes a name and string conversion functions and returns an XML converter that represents an attribute. Attributes must not be used in repetitions and do not represent an XML element.

adapt :: (a → b,b → a) → XmlConv c d a → XmlConv c d b

Converts between arbitrary XML converters for different types.

opt :: XmlConv a b c → XmlConv NotRepeatable NoElem (Maybe c)

Creates a converter for arbitrary optional XML data. Optional XML data must not be used in repetitions and does not represent an XML element.

rep :: XmlConv Repeatable a b → XmlConv NotRepeatable NoElem [b]

Takes an XML converter representing repeatable data and returns an XML converter that represents repetitions of this data. Repetitions must not be used in other repetitions and do not represent XML elements.

aInt :: String → XmlConv NotRepeatable NoElem Int

Creates an XML converter for integer attributes. Integer attributes must not be used in repetitions and do not represent XML elements.

aFloat :: String → XmlConv NotRepeatable NoElem Float

Creates an XML converter for float attributes. Float attributes must not be used in repetitions and do not represent XML elements.

aChar :: String → XmlConv NotRepeatable NoElem Char

Creates an XML converter for character attributes. Character attributes must not be used in repetitions and do not represent XML elements.

aString :: String → XmlConv NotRepeatable NoElem String
Creates an XML converter for string attributes. String attributes must not be used in repetitions and do not represent XML elements.

\[ \text{aBool :: String} \to \text{String} \to \text{String} \to \text{XmlConv NotRepeatable NoElem Bool} \]

Creates an XML converter for boolean attributes. Boolean attributes must not be used in repetitions and do not represent XML elements.

\[ \text{eInt :: String} \to \text{XmlConv Repeatable Elem Int} \]

Creates an XML converter for integer elements. Integer elements may be used in repetitions.

\[ \text{eFloat :: String} \to \text{XmlConv Repeatable Elem Float} \]

Creates an XML converter for float elements. Float elements may be used in repetitions.

\[ \text{eChar :: String} \to \text{XmlConv Repeatable Elem Char} \]

Creates an XML converter for character elements. Character elements may be used in repetitions.

\[ \text{eString :: String} \to \text{XmlConv Repeatable Elem String} \]

Creates an XML converter for string elements. String elements may be used in repetitions.

\[ \text{eBool :: String} \to \text{String} \to \text{XmlConv Repeatable Elem Bool} \]

Creates an XML converter for boolean elements. Boolean elements may be used in repetitions.

\[ \text{eEmpty :: String} \to \text{a} \to \text{XmlConv Repeatable Elem a} \]

Takes a name and a value and creates an empty XML element that represents the given value. The created element may be used in repetitions.

\[ \text{eOpt :: String} \to \text{XmlConv a b c} \to \text{XmlConv Repeatable Elem (Maybe c)} \]

Creates an XML converter that represents an element containing optional XML data. The created element may be used in repetitions.

\[ \text{eRep :: String} \to \text{XmlConv Repeatable a b} \to \text{XmlConv Repeatable Elem [b]} \]

Creates an XML converter that represents an element containing repeated XML data. The created element may be used in repetitions.

\[ \text{seq1 :: (a} \to \text{b)} \to \text{XmlConv c d a} \to \text{XmlConv c NoElem b} \]

Creates an XML converter representing a sequence of arbitrary XML data. The sequence must not be used in repetitions and does not represent an XML element.

\[ \text{repSeq1 :: (a} \to \text{b)} \to \text{XmlConv Repeatable c a} \to \text{XmlConv NotRepeatable NoElem [b]} \]
Creates an XML converter that represents a repetition of a sequence of repeatable XML data. The repetition may be used in other repetitions but does not represent an XML element. This combinator is provided because converters for repeatable sequences cannot be constructed by the seq combinators.

\[
eSeq1 :: \text{String} \rightarrow (a \rightarrow b) \rightarrow \text{XmlConv} \; c \; d \; a \rightarrow \text{XmlConv} \; \text{Repeatable} \; \text{Elem} \; b
\]

Creates an XML converter for compound values represented as an XML element with children that correspond to the values components. The element can be used in repetitions.

\[
eRepSeq1 :: \text{String} \rightarrow (a \rightarrow b) \rightarrow \text{XmlConv} \; \text{Repeatable} \; c \; a \rightarrow \text{XmlConv} \; \text{Repeatable} \; \text{Elem} \; [b]
\]

Creates an XML converter for repetitions of sequences represented as an XML element that can be used in repetitions.

\[
\text{seq2} :: (a \rightarrow b \rightarrow c) \rightarrow \text{XmlConv} \; d \; e \; a \rightarrow \text{XmlConv} \; f \; g \; b \rightarrow \text{XmlConv} \; \text{NotRepeatable} \; \text{NoElem} \; c
\]

Creates an XML converter representing a sequence of arbitrary XML data. The sequence must not be used in repetitions and does not represent an XML element.

\[
\text{repSeq2} :: (a \rightarrow b \rightarrow c) \rightarrow \text{XmlConv} \; \text{Repeatable} \; d \; a \rightarrow \text{XmlConv} \; \text{Repeatable} \; e \; b \rightarrow \text{XmlConv} \; \text{NotRepeatable} \; \text{NoElem} \; [c]
\]

Creates an XML converter that represents a repetition of a sequence of repeatable XML data. The repetition may be used in other repetitions and does not represent an XML element. This combinator is provided because converters for repeatable sequences cannot be constructed by the seq combinators.

\[
eSeq2 :: \text{String} \rightarrow (a \rightarrow b \rightarrow c) \rightarrow \text{XmlConv} \; d \; e \; a \rightarrow \text{XmlConv} \; f \; g \; b \rightarrow \text{XmlConv} \; \text{Repeatable} \; \text{Elem} \; c
\]

Creates an XML converter for compound values represented as an XML element with children that correspond to the values components. The element can be used in repetitions.

\[
eRepSeq2 :: \text{String} \rightarrow (a \rightarrow b \rightarrow c) \rightarrow \text{XmlConv} \; \text{Repeatable} \; d \; a \rightarrow \text{XmlConv} \; \text{Repeatable} \; e \; b \rightarrow \text{XmlConv} \; \text{Repeatable} \; \text{Elem} \; [c]
\]

Creates an XML converter for repetitions of sequences represented as an XML element that can be used in repetitions.

\[
\text{seq3} :: (a \rightarrow b \rightarrow c \rightarrow d) \rightarrow \text{XmlConv} \; e \; f \; a \rightarrow \text{XmlConv} \; g \; h \; b \rightarrow \text{XmlConv} \; i \; j \; c \rightarrow \text{XmlConv} \; \text{NotRepeatable} \; \text{NoElem} \; d
\]

Creates an XML converter representing a sequence of arbitrary XML data. The sequence must not be used in repetitions and does not represent an XML element.
repSeq3 :: (a → b → c → d) → XmlConv Repeatable e a → XmlConv Repeatable f b → XmlConv Repeatable g c → XmlConv NotRepeatable NoElem [d]

Creates an XML converter that represents a repetition of a sequence of repeatable XML data. The repetition may be used in other repetitions and does not represent an XML element. This combinator is provided because converters for repeatable sequences cannot be constructed by the seq combinators.

eSeq3 :: String → (a → b → c → d) → XmlConv e f a → XmlConv g h b → XmlConv i j c → XmlConv Repeatable Elem d

Creates an XML converter for compound values represented as an XML element with children that correspond to the values components. The element can be used in repetitions.

eRepSeq3 :: String → (a → b → c → d) → XmlConv Repeatable e a → XmlConv Repeatable f b → XmlConv Repeatable g c → XmlConv Repeatable Elem [d]

Creates an XML converter for repetitions of sequences represented as an XML element that can be used in repetitions.

seq4 :: (a → b → c → d → e) → XmlConv f g a → XmlConv h i b → XmlConv j k c → XmlConv l m d → XmlConv NotRepeatable NoElem e

Creates an XML converter representing a sequence of arbitrary XML data. The sequence must not be used in repetitions and does not represent an XML element.

repSeq4 :: (a → b → c → d → e) → XmlConv Repeatable f a → XmlConv Repeatable g b → XmlConv Repeatable h c → XmlConv Repeatable i d → XmlConv NotRepeatable NoElem [e]

Creates an XML converter that represents a repetition of a sequence of repeatable XML data. The repetition may be used in other repetitions and does not represent an XML element. This combinator is provided because converters for repeatable sequences cannot be constructed by the seq combinators.

eSeq4 :: String → (a → b → c → d → e) → XmlConv f g a → XmlConv h i b → XmlConv j k c → XmlConv l m d → XmlConv Repeatable Elem e

Creates an XML converter for compound values represented as an XML element with children that correspond to the values components. The element can be used in repetitions.

eRepSeq4 :: String → (a → b → c → d → e) → XmlConv Repeatable f a → XmlConv Repeatable g b → XmlConv Repeatable h c → XmlConv Repeatable i d → XmlConv Repeatable Elem [e]

Creates an XML converter for repetitions of sequences represented as an XML element that can be used in repetitions.
seq5 :: (a -> b -> c -> d -> e -> f) -> XmlConv g h a -> XmlConv i j b -> XmlConv k l c -> XmlConv m n d -> XmlConv o p e -> XmlConv NotRepeatable NoElem f

Creates an XML converter representing a sequence of arbitrary XML data. The sequence must not be used in repetitions and does not represent an XML element.

repSeq5 :: (a -> b -> c -> d -> e -> f) -> XmlConv Repeatable g a -> XmlConv Repeatable h b -> XmlConv Repeatable i c -> XmlConv Repeatable j d -> XmlConv Repeatable k e -> XmlConv NotRepeatable NoElem f

Creates an XML converter that represents a repetition of a sequence of repeatable XML data. The repetition may be used in other repetitions and does not represent an XML element. This combinator is provided because converters for repeatable sequences cannot be constructed by the seq combinators.

eSeq5 :: String -> (a -> b -> c -> d -> e -> f) -> XmlConv g h a -> XmlConv i j b -> XmlConv k l c -> XmlConv m n d -> XmlConv o p e -> XmlConv Repeatable Elem f

Creates an XML converter for compound values represented as an XML element with children that correspond to the values components. The element can be used in repetitions.

eRepSeq5 :: String -> (a -> b -> c -> d -> e -> f) -> XmlConv Repeatable g a -> XmlConv Repeatable h b -> XmlConv Repeatable i c -> XmlConv Repeatable j d -> XmlConv Repeatable k e -> XmlConv Repeatable Elem f

Creates an XML converter for repetitions of sequences represented as an XML element that can be used in repetitions.

seq6 :: (a -> b -> c -> d -> e -> f -> g) -> XmlConv h i a -> XmlConv j k b -> XmlConv l m c -> XmlConv n o d -> XmlConv p q e -> XmlConv r s f -> XmlConv NotRepeatable NoElem g

Creates an XML converter representing a sequence of arbitrary XML data. The sequence must not be used in repetitions and does not represent an XML element.

repSeq6 :: (a -> b -> c -> d -> e -> f -> g) -> XmlConv Repeatable h a -> XmlConv Repeatable i b -> XmlConv Repeatable j c -> XmlConv Repeatable k d -> XmlConv Repeatable l e -> XmlConv Repeatable m f -> XmlConv NotRepeatable NoElem g

Creates an XML converter that represents a repetition of a sequence of repeatable XML data. The repetition may be used in other repetitions and does not represent an XML element. This combinator is provided because converters for repeatable sequences cannot be constructed by the seq combinators.

eSeq6 :: String -> (a -> b -> c -> d -> e -> f -> g) -> XmlConv h i a -> XmlConv j k b -> XmlConv l m c -> XmlConv n o d -> XmlConv p q e -> XmlConv r s f -> XmlConv Repeatable Elem g

216
Creates an XML converter for compound values represented as an XML element with children that correspond to the values components. The element can be used in repetitions.

\[
eRepSeq6 :: \text{String} \rightarrow (a \rightarrow b \rightarrow c \rightarrow d \rightarrow e \rightarrow f \rightarrow g) \rightarrow \text{XmlConv Repeatable} \ h \ a \rightarrow \text{XmlConv Repeatable} \ i \ b \rightarrow \text{XmlConv Repeatable} \ j \ c \rightarrow \text{XmlConv Repeatable} \ k \ d \rightarrow \text{XmlConv Repeatable} \ l \ e \rightarrow \text{XmlConv Repeatable} \ m \ f \rightarrow \text{XmlConv Repeatable} \ \text{Elem} \ [g]
\]

Creates an XML converter for repetitions of sequences represented as an XML element that can be used in repetitions.

### A.5 Libraries for Meta-Programming

#### A.5.1 Library AbstractCurry

Library to support meta-programming in Curry.

This library contains a definition for representing Curry programs in Curry (type "CurryProg") and an I/O action to read Curry programs and transform them into this abstract representation (function "readCurry").

Note this defines a slightly new format for AbstractCurry in comparison to the first proposal of 2003.

Assumption: an abstract Curry program is stored in file with extension .acy

**Exported types:**

- type MName = String
  
  A module name.

- type QName = (String,String)
  
  The data type for representing qualified names. In AbstractCurry all names are qualified to avoid name clashes. The first component is the module name and the second component the unqualified name as it occurs in the source program.

- type CTVarIName = (Int,String)
  
  The type for representing type variables. They are represented by (i,n) where i is a type variable index which is unique inside a function and n is a name (if possible, the name written in the source program).

- type CField a = ((String,String),a)
  
  Labeled record fields

- type Arity = Int
  
  Function arity

- type CVarIName = (Int,String)
Data types for representing object variables. Object variables occurring in expressions are represented by \((\text{Var } i)\) where \(i\) is a variable index.

\textbf{data CVisibility}

Data type to specify the visibility of various entities.

\textit{Exported constructors:}

- Public :: CVisibility
- Private :: CVisibility

\textbf{data CurryProg}

Data type for representing a Curry module in the intermediate form. A value of this data type has the form

\((\text{CProg modname imports typedecls functions opdecls})\)

where modname: name of this module, imports: list of modules names that are imported, typedecls: Type declarations functions: Function declarations opdecls: Operator precedence declarations

\textit{Exported constructors:}

- CurryProg :: String \(\rightarrow\) [String] \(\rightarrow\) [CTypeDecl] \(\rightarrow\) [CFuncDecl] \(\rightarrow\) [COpDecl] \(\rightarrow\) CurryProg

\textbf{data CTypeDecl}

Data type for representing definitions of algebraic data types and type synonyms.

A data type definition of the form

\[\text{data } t \ x_1 \ldots x_n = \ldots | \ c \ t_1 \ldots t_{k_c} | \ldots\]

is represented by the Curry term

\[(\text{CType } t \ v \ [i_1,\ldots, i_n] \ [\ldots, (\text{CCons } c \ k_c \ v \ [t_1,\ldots, t_{k_c}])\ldots])\]

where each \(i_j\) is the index of the type variable \(x_j\).

Note: the type variable indices are unique inside each type declaration and are usually numbered from 0

Thus, a data type declaration consists of the name of the data type, a list of type parameters and a list of constructor declarations.

\textit{Exported constructors:}
• CType :: (String,String) → CVisibility → [(Int,String)] → CConsDecl → CTypeDecl

• CTypeSyn :: (String,String) → CVisibility → [(Int,String)] → CTypeExpr → CTypeDecl

• CNewType :: (String,String) → CVisibility → [(Int,String)] → CConsDecl → CTypeDecl

data CConsDecl

A constructor declaration consists of the name of the constructor and a list of the argument types of the constructor. The arity equals the number of types.

*Exported constructors:*

• CCons :: (String,String) → CVisibility → [CTypeExpr] → CConsDecl

• CRecord :: (String,String) → CVisibility → [CFieldDecl] → CConsDecl

data CFieldDecl

A record field declaration consists of the name of the the label, the visibility and its corresponding type.

*Exported constructors:*

• CField :: (String,String) → CVisibility → CTypeExpr → CFieldDecl

data CTypeExpr

Type expression. A type expression is either a type variable, a function type, or a type constructor application.

Note: the names of the predefined type constructors are "Int", "Float", "Bool", "Char", "IO", "Success", "()" (unit type), "(...)" (tuple types), "[]" (list type)

*Exported constructors:*

• CTVar :: (Int,String) → CTypeExpr

• CFuncType :: CTypeExpr → CTypeExpr → CTypeExpr

• CTCons :: (String,String) → [CTypeExpr] → CTypeExpr

data COpDecl

Data type for operator declarations. An operator declaration "fix p n" in Curry corresponds to the AbstractCurry term (COp n fix p).

*Exported constructors:*
• \texttt{COp :: (String, String) \rightarrow CFixity \rightarrow Int \rightarrow COpDecl}

\textbf{data CFixity}

Data type for operator associativity

\textit{Exported constructors:}

• \texttt{CInfixOp :: CFixity}
• \texttt{CInfixlOp :: CFixity}
• \texttt{CInfixrOp :: CFixity}

\textbf{data CFuncDecl}

Data type for representing function declarations.

A function declaration in AbstractCurry is a term of the form
\((\texttt{CFunc name arity visibility type (CRules eval [CRule rule1,...,rulek])})\)
and represents the function \texttt{name} defined by the rules \texttt{rule1,...,rulek}.

Note: the variable indices are unique inside each rule

Thus, a function declaration consists of the name, arity, type, and a list of rules.

A function declaration with the constructor \texttt{CmtFunc} is similarly to \texttt{CFunc} but has
a comment as an additional first argument. This comment could be used by pretty
printers that generate a readable Curry program containing documentation comments.

\textit{Exported constructors:}

• \texttt{CFunc :: (String, String) \rightarrow Int \rightarrow CVisibility \rightarrow CTypeExpr \rightarrow [CRule] \rightarrow CFuncDecl}
• \texttt{CmtFunc :: String \rightarrow (String, String) \rightarrow Int \rightarrow CVisibility \rightarrow CTypeExpr \rightarrow [CRule] \rightarrow CFuncDecl}

\textbf{data CRule}

The general form of a function rule. It consists of a list of patterns (left-hand side) and
the right-hand side for these patterns.

\textit{Exported constructors:}

• \texttt{CRule :: [CPattern] \rightarrow CRhs \rightarrow CRule}

\textbf{data CRhs}

Right-hand-side of a \texttt{CRule} or a \texttt{case} expression. It is either a simple unconditional
right-hand side or a list of guards with their corresponding right-hand sides, and a list
of local declarations.
Exported constructors:

- CSimpleRhs :: CExpr → [CLocalDecl] → CRhs
- CGuardedRhs :: [(CExpr,CExpr)] → [CLocalDecl] → CRhs

data CLocalDecl

Data type for representing local (let/where) declarations

Exported constructors:

- CLocalFunc :: CFuncDecl → CLocalDecl
- CLocalPat :: CPattern → CRhs → CLocalDecl
- CLocalVars :: [(Int,String)] → CLocalDecl

data CPattern

Data type for representing pattern expressions.

Exported constructors:

- CPVar :: (Int,String) → CPattern
- CPLit :: CLiteral → CPattern
- CPComb :: (String,String) → [CPattern] → CPattern
- CPAs :: (Int,String) → CPattern → CPattern
- CPFuncComb :: (String,String) → [CPattern] → CPattern
- CPLazy :: CPattern → CPattern
- CRecord :: (String,String) → [((String,String),CPattern)] → CPattern

data CExpr

Data type for representing Curry expressions.

Exported constructors:

- CVar :: (Int,String) → CExpr
- CLit :: CLiteral → CExpr
- CSymbol :: (String,String) → CExpr
- CApply :: CExpr → CExpr → CExpr
- CLambda :: [CPattern] → CExpr → CExpr

221
• CLetDecl :: [CLocalDecl] → CExpr → CExpr
• CDoExpr :: [CStatement] → CExpr
• CListComp :: CExpr → [CStatement] → CExpr
• CCase :: CCaseType → CExpr → [(CPattern, CRhs)] → CExpr
• CTyped :: CExpr → CTypeExpr → CExpr
• CRecConstr :: (String, String) → [((String, String), CExpr)] → CExpr
• CRecUpdate :: CExpr → [((String, String), CExpr)] → CExpr

data CLiteral

  Data type for representing literals occurring in an expression. It is either an integer, a
  float, or a character constant.

Exported constructors:

• CIntc :: Int → CLiteral
• CFloatc :: Float → CLiteral
• CCharc :: Char → CLiteral
• CStringc :: String → CLiteral

data CStatement

  Data type for representing statements in do expressions and list comprehensions.

Exported constructors:

• CSEexpr :: CExpr → CStatement
• CSPat :: CPattern → CExpr → CStatement
• CSLet :: [CLocalDecl] → CStatement

data CCaseType

  Type of case expressions

Exported constructors:

• CRigid :: CCaseType
• CFlex :: CCaseType
Exported functions:

version :: String

    Current version of AbstractCurry

readCurry :: String → IO CurryProg

    I/O action which parses a Curry program and returns the corresponding typed Abstract
    Curry program. Thus, the argument is the file name without suffix ”.curry” or ”.lcurry”)
    and the result is a Curry term representing this program.

readUntypedCurry :: String → IO CurryProg

    I/O action which parses a Curry program and returns the corresponding untyped Ab-
    stract Curry program. Thus, the argument is the file name without suffix ”.curry” or
    ”.lcurry”) and the result is a Curry term representing this program.

readCurryWithParseOptions :: String → FrontendParams → IO CurryProg

    I/O action which reads a typed Curry program from a file (with extension ”.acy”) with
    respect to some parser options. This I/O action is used by the standard action
    readCurry. It is currently predefined only in Curry2Prolog.

readUntypedCurryWithParseOptions :: String → FrontendParams → IO CurryProg

    I/O action which reads an untyped Curry program from a file (with extension
    ”.uacy”) with respect to some parser options. For more details see function
    readCurryWithParseOptions

abstractCurryFileName :: String → String

    Transforms a name of a Curry program (with or without suffix ”.curry” or ”.lcurry”) into
    the name of the file containing the corresponding AbstractCurry program.

untypedAbstractCurryFileName :: String → String

    Transforms a name of a Curry program (with or without suffix ”.curry” or ”.lcurry”) into
    the name of the file containing the corresponding untyped AbstractCurry program.

readAbstractCurryFile :: String → IO CurryProg

    I/O action which reads an AbstractCurry program from a file in ”.acy” format. In
    contrast to readCurry, this action does not parse a source program. Thus, the argument
    must be the name of an existing file (with suffix ”.acy”) containing an AbstractCurry
    program in ”.acy” format and the result is a Curry term representing this program. It
    is currently predefined only in Curry2Prolog.

tryReadACYFile :: String → IO (Maybe CurryProg)

    Tries to read an AbstractCurry file and returns
• Left err, where err specifies the error occurred
• Right prog, where prog is the AbstractCurry program

writeAbstractCurryFile :: String → CurryProg → IO ()

Writes an AbstractCurry program into a file in ".acy" format. The first argument must be the name of the target file (with suffix ".acy").

A.5.2 Library AbstractCurryGoodies

This module provides some useful functions to write programs that generate AbstractCurry programs more compact and readable.

Exported functions:

(\times\times) :: CTypeExpr → CTypeExpr → CTypeExpr

A function type.

baseType :: (String,String) → CTypeExpr

A base type.

listType :: CTypeExpr → CTypeExpr

Constructs a list type from an element type.

tupleType :: [CTypeExpr] → CTypeExpr

Constructs a tuple type from list of component types.

ioType :: CTypeExpr → CTypeExpr

Constructs an IO type from a type.

maybeType :: CTypeExpr → CTypeExpr

Constructs a Maybe type from element type.

stringType :: CTypeExpr

The type expression of the String type.

intType :: CTypeExpr

The type expression of the Int type.

floatType :: CTypeExpr

The type expression of the Float type.

boolType :: CTypeExpr

The type expression of the Bool type.
unitType :: CTypeExpr
    The type expression of the unit type.

dateType :: CTypeExpr
    The type expression of the Time.CalendarTime type.

typeName :: CTypeDecl → (String,String)
    Returns the name of a given type declaration

typeVis :: CTypeDecl → CVisibility
    Returns the visibility of a given type declaration

typeCons :: CTypeDecl → [CConsDecl]
    Returns the constructors of a given type declaration

funcName :: CFuncDecl → (String,String)
    Returns the name of a given function declaration

funcVis :: CFuncDecl → CVisibility
    Returns the visibility of a given function declaration

consVis :: CConsDecl → CVisibility
    Returns the visibility of a given constructor declaration

isBaseType :: CTypeExpr → Bool
    Returns true if the type expression is a base type.

isPolyType :: CTypeExpr → Bool
    Returns true if the type expression contains type variables.

isFunctionalType :: CTypeExpr → Bool
    Returns true if the type expression is a functional type.

isIOType :: CTypeExpr → Bool
    Returns true if the type expression is (IO t).

is10ReturnType :: CTypeExpr → Bool
    Returns true if the type expression is (IO t) with t/=() and t is not functional

argTypes :: CTypeExpr → [CTypeExpr]
    Returns all argument types from a functional type
resultType :: CTypeExpr → CTypeExpr

Return the result type from a (nested) functional type.

tvarsOfType :: CTypeExpr → [(Int,String)]

Returns all type variables occurring in a type expression.

modsOfType :: CTypeExpr → [String]

Returns all modules used in the given type.

cfunc :: (String,String) → Int → CVvisibility → CTypeExpr → [CRule] → CFuncDecl

Constructs a function declaration from a given qualified function name, arity, visibility, type expression and list of defining rules.

cmtfunc :: String → (String,String) → Int → CVvisibility → CTypeExpr → [CRule] → CFuncDecl

Constructs a function declaration from a given comment, qualified function name, arity, visibility, type expression and list of defining rules.

simpleRule :: [CPattern] → CExpr → CRule

Constructs a simple rule with a pattern list and an unconditional right-hand side.

noGuard :: CExpr → (CExpr,CExpr)

Constructs a guarded expression with the trivial guard.

applyF :: (String,String) → [CExpr] → CExpr

An application of a qualified function name to a list of arguments.

applyE :: CExpr → [CExpr] → CExpr

An application of an expression to a list of arguments.

constF :: (String,String) → CExpr

A constant, i.e., an application without arguments.

applyV :: (Int,String) → [CExpr] → CExpr

An application of a variable to a list of arguments.

applyJust :: CExpr → CExpr

applyMaybe :: CExpr → CExpr → CExpr → CExpr
tupleExpr :: [CExpr] → CExpr
Constructs a tuple expression from list of component expressions.
cBranch :: CPattern → CExpr → (CPattern,CRhs)
Constructs from a pattern and an expression a branch for a case expression.
tuplePattern :: [CPattern] → CPattern
Constructs a tuple pattern from list of component patterns.
pVars :: Int → [CPattern]
Constructs, for given n, a list of n PVars starting from 0.
pChar :: Char → CPattern
Converts a character into a pattern.
pNil :: CPattern
Constructs an empty list pattern.
listPattern :: [CPattern] → CPattern
Constructs a list pattern from list of component patterns.
stringPattern :: String → CPattern
Converts a string into a pattern representing this string.
list2ac :: [CExpr] → CExpr
Converts a list of AbstractCurry expressions into an AbstractCurry representation of this list.
cChar :: Char → CExpr
Converts a character into an AbstractCurry expression.
string2ac :: String → CExpr
Converts a string into an AbstractCurry representation of this string.
pre :: String → (String,String)
Converts a string into a qualified name of the Prelude.
isPrelude :: String → Bool
Tests whether a module name is the prelude.
toVar :: Int → CExpr
Converts an index i into a variable named xi.
cvar :: String → CExpr
Converts a string into a variable with index 1.
cpvar :: String → CPattern
Converts a string into a pattern variable with index 1.
ctvar :: String → CTypeExpr
Converts a string into a type variable with index 1.
A.5.3 Library AbstractCurryPrinter

A pretty printer for AbstractCurry programs. This library defines a function "showProg" that shows an AbstractCurry program in standard Curry syntax.

Exported functions:

showProg :: CurryProg → String

Shows an AbstractCurry program in standard Curry syntax. The export list contains the public functions and the types with their data constructors (if all data constructors are public), otherwise only the type constructors. The potential comments in function declarations are formatted as documentation comments.

showTypeDecls :: [CTypeDecl] → String

Shows a list of AbstractCurry type declarations in standard Curry syntax.

showTypeDecl :: CTypeDecl → String

Shows an AbstractCurry type declaration in standard Curry syntax.

showTypeExpr :: Bool → CTypeExpr → String

Shows an AbstractCurry type expression in standard Curry syntax. If the first argument is True, the type expression is enclosed in brackets.

showFuncDecl :: CFuncDecl → String

Shows an AbstractCurry function declaration in standard Curry syntax.

showExpr :: CExpr → String

Shows an AbstractCurry expression in standard Curry syntax.

showPattern :: CPattern → String

A.5.4 Library AnnotatedFlatCurry

An annotatable version of FlatCurry. This module contains a version of FlatCurry’s abstract syntax tree which can be annotated with arbitrary information due to a polymorphic type parameter. For instance, this could be used to annotate function declarations and expressions with their corresponding type. For more information about the abstract syntax tree of FlatCurry, see the documentation of the respective module.
Exported types:

```haskell
type Arity = Int
  -- Arity of a function declaration
```

data AProg

  -- Annotated FlatCurry program (corresponds to a module)

  Exported constructors:

  • AProg :: String → [String] → [TypeDecl] → [AFuncDecl a] → [OpDecl] → AProg a

```

data AFuncDecl

  -- Annotated function declaration

  Exported constructors:

  • AFunc :: (String,String) → Int → Visibility → TypeExpr → (ARule a) → AFuncDecl a

```

data ARule

  -- Annotated function rule

  Exported constructors:

  • ARule :: a → [(Int,a)] → (AExpr a) → ARule a
  • AExternal :: a → String → ARule a

```

data AExpr

  -- Annotated expression

  Exported constructors:

  • AVar :: a → Int → AExpr a
  • ALit :: a → Literal → AExpr a
  • AComb :: a → CombType → ((String,String),a) → [AExpr a] → AExpr a
  • ALet :: a → [((Int,a),AExpr a)] → (AExpr a) → AExpr a
  • AFree :: a → [(Int,a)] → (AExpr a) → AExpr a
  • AOr :: a → (AExpr a) → (AExpr a) → AExpr a
  • ACase :: a → CaseType → (AExpr a) → [ABranchExpr a] → AExpr a
- \texttt{ATyped :: a \rightarrow (AExpr a) \rightarrow TypeExpr \rightarrow AExpr a}

\textbf{data ABranchExpr}

Annotated case branch

\textit{Exported constructors:}

- \texttt{ABranch :: (APattern a) \rightarrow (AExpr a) \rightarrow ABranchExpr a}

\textbf{data APattern}

Annotated pattern

\textit{Exported constructors:}

- \texttt{APattern :: a \rightarrow ((String,String),a) \rightarrow [(Int,a)] \rightarrow APattern a}
- \texttt{ALPattern :: a \rightarrow Literal \rightarrow APattern a}

\textbf{A.5.5 Library AnnotatedFlatCurryGoodies}

This library provides selector functions, test and update operations as well as some useful auxiliary functions for FlatCurry data terms. Most of the provided functions are based on general transformation functions that replace constructors with user-defined functions. For recursive datatypes the transformations are defined inductively over the term structure. This is quite usual for transformations on FlatCurry terms, so the provided functions can be used to implement specific transformations without having to explicitly state the recursion. Essentially, the tedious part of such transformations - descend in fairly complex term structures - is abstracted away, which hopefully makes the code more clear and brief.

\textbf{Exported types:}

\begin{verbatim}
export type Update a b = (b \rightarrow b) \rightarrow a \rightarrow a
\end{verbatim}

\textbf{Exported functions:}

\begin{verbatim}
trProg :: (String \rightarrow [String] \rightarrow [TypeDecl] \rightarrow [AFuncDecl a] \rightarrow [OpDecl] \rightarrow b) \rightarrow AProg a \rightarrow b

transform program

progName :: AProg a \rightarrow String

get name from program

progImports :: AProg a \rightarrow [String]

get imports from program
\end{verbatim}
progTypes :: AProg a → [TypeDecl]
  get type declarations from program

progFuncs :: AProg a → [AFuncDecl a]
  get functions from program

progOps :: AProg a → [OpDecl]
  get infix operators from program

updProg :: (String → String) → ([String] → [String]) → ([TypeDecl] → [TypeDecl]) → ([AFuncDecl a] → [AFuncDecl a]) → ([OpDecl] → [OpDecl]) → AProg a → AProg a
  update program

updProgName :: (String → String) → AProg a → AProg a
  update name of program

updProgImports :: ([String] → [String]) → AProg a → AProg a
  update imports of program

updProgTypes :: ([TypeDecl] → [TypeDecl]) → AProg a → AProg a
  update type declarations of program

updProgFuncs :: ([AFuncDecl a] → [AFuncDecl a]) → AProg a → AProg a
  update functions of program

updProgOps :: ([OpDecl] → [OpDecl]) → AProg a → AProg a
  update infix operators of program

allVarsInProg :: AProg a → [Int]
  get all program variables (also from patterns)

updProgExps :: (AExpr a → AExpr a) → AProg a → AProg a
  lift transformation on expressions to program

rnmAllVarsInProg :: (Int → Int) → AProg a → AProg a
  rename programs variables

updQNamesInProg :: ((String,String) → (String,String)) → AProg a → AProg a
  update all qualified names in program

rnmProg :: String → AProg a → AProg a
rename program (update name of and all qualified names in program)

\[ \text{trType :: ((String,String) → Visibility → [Int] → [ConsDecl] → a) → ((String,String) → Visibility → [Int] → TypeExpr → a) → TypeDecl → a} \]

transform type declaration

\[ \text{typeName :: TypeDecl → (String,String)} \]

get name of type declaration

\[ \text{typeVisibility :: TypeDecl → Visibility} \]

get visibility of type declaration

\[ \text{typeParams :: TypeDecl → [Int]} \]

get type parameters of type declaration

\[ \text{typeConsDecls :: TypeDecl → [ConsDecl]} \]

get constructor declarations from type declaration

\[ \text{typeSyn :: TypeDecl → TypeExpr} \]

get synonym of type declaration

\[ \text{isTypeSyn :: TypeDecl → Bool} \]

is type declaration a type synonym?

\[ \text{updType :: ((String,String) → (String,String)) → (Visibility → Visibility)} \]
\[ \text{→ ([Int] → [Int]) → ([ConsDecl] → [ConsDecl]) → (TypeExpr → TypeExpr)} \]
\[ \text{→ TypeDecl → TypeDecl} \]

update type declaration

\[ \text{updTypeName :: ((String,String) → (String,String)) → TypeDecl → TypeDecl} \]

update name of type declaration

\[ \text{updTypeVisibility :: (Visibility → Visibility)} \]
\[ \text{→ TypeDecl → TypeDecl} \]

update visibility of type declaration

\[ \text{updTypeParams :: ([Int] → [Int]) → TypeDecl → TypeDecl} \]

update type parameters of type declaration

\[ \text{updTypeConsDecls :: ([ConsDecl] → [ConsDecl]) → TypeDecl → TypeDecl} \]

update constructor declarations of type declaration

\[ \text{updTypeSynonym :: (TypeExpr → TypeExpr)} \]
\[ \text{→ TypeDecl → TypeDecl} \]
update synonym of type declaration

 updQNamesInType :: ((String,String) -> (String,String)) -> TypeDecl -> TypeDecl

 update all qualified names in type declaration

 trCons :: ((String,String) -> Int -> Visibility -> [TypeExpr] -> a) -> ConsDecl -> a

 transform constructor declaration

 consName :: ConsDecl -> (String,String)

 get name of constructor declaration

 consArity :: ConsDecl -> Int

 get arity of constructor declaration

 consVisibility :: ConsDecl -> Visibility

 get visibility of constructor declaration

 consArgs :: ConsDecl -> [TypeExpr]

 get arguments of constructor declaration

 updCons :: ((String,String) -> (String,String)) -> (Int -> Int) -> (Visibility -> Visibility) -> ([TypeExpr] -> [TypeExpr]) -> ConsDecl -> ConsDecl

 update constructor declaration

 updConsName :: ((String,String) -> (String,String)) -> ConsDecl -> ConsDecl

 update name of constructor declaration

 updConsArity :: (Int -> Int) -> ConsDecl -> ConsDecl

 update arity of constructor declaration

 updConsVisibility :: (Visibility -> Visibility) -> ConsDecl -> ConsDecl

 update visibility of constructor declaration

 updConsArgs :: ([TypeExpr] -> [TypeExpr]) -> ConsDecl -> ConsDecl

 update arguments of constructor declaration

 updQNamesInConsDecl :: ((String,String) -> (String,String)) -> ConsDecl -> ConsDecl

 update all qualified names in constructor declaration

 tVarIndex :: TypeExpr -> Int
get index from type variable

\[ \text{domain :: TypeExpr} \rightarrow \text{TypeExpr} \]

get domain from functional type

\[ \text{range :: TypeExpr} \rightarrow \text{TypeExpr} \]

get range from functional type

\[ \text{tConsName :: TypeExpr} \rightarrow (\text{String, String}) \]

get name from constructed type

\[ \text{tConsArgs :: TypeExpr} \rightarrow \text{[TypeExpr]} \]

get arguments from constructed type

\[ \text{trTypeExpr :: (Int \rightarrow a) \rightarrow ((\text{String,String}) \rightarrow [a] \rightarrow a) \rightarrow (a \rightarrow a \rightarrow a) \rightarrow TypeExpr \rightarrow a} \]

\[ \text{isTVar :: TypeExpr} \rightarrow \text{Bool} \]

is type expression a type variable?

\[ \text{isTCons :: TypeExpr} \rightarrow \text{Bool} \]

is type declaration a constructed type?

\[ \text{isFuncType :: TypeExpr} \rightarrow \text{Bool} \]

is type declaration a functional type?

\[ \text{updTVars :: (Int \rightarrow \text{TypeExpr}) \rightarrow \text{TypeExpr} \rightarrow \text{TypeExpr}} \]

update all type variables

\[ \text{updTCons :: ((\text{String,String}) \rightarrow [\text{TypeExpr}] \rightarrow \text{TypeExpr}) \rightarrow \text{TypeExpr} \rightarrow \text{TypeExpr}} \]

update all type constructors

\[ \text{updFuncTypes :: (\text{TypeExpr} \rightarrow \text{TypeExpr} \rightarrow \text{TypeExpr}) \rightarrow \text{TypeExpr} \rightarrow \text{TypeExpr}} \]

update all functional types

\[ \text{argTypes :: TypeExpr} \rightarrow \text{[TypeExpr]} \]

get argument types from functional type

\[ \text{resultType :: TypeExpr} \rightarrow \text{TypeExpr} \]

get result type from (nested) functional type

\[ \text{rnmAllVarsInTypeExpr :: (Int \rightarrow \text{Int}) \rightarrow \text{TypeExpr} \rightarrow \text{TypeExpr}} \]
rename variables in type expression

\[
\text{updQNamesInTypeExpr :: ((String,String) \rightarrow (String,String)) \rightarrow TypeExpr \rightarrow TypeExpr}
\]

update all qualified names in type expression

\[
\text{trOp :: ((String,String) \rightarrow Fixity \rightarrow Int \rightarrow a) \rightarrow OpDecl \rightarrow a}
\]

transform operator declaration

\[
\text{opName :: OpDecl \rightarrow (String,String)}
\]

get name from operator declaration

\[
\text{opFixity :: OpDecl \rightarrow Fixity}
\]

get fixity of operator declaration

\[
\text{opPrecedence :: OpDecl \rightarrow Int}
\]

get precedence of operator declaration

\[
\text{updOp :: ((String,String) \rightarrow (String,String)) \rightarrow (Fixity \rightarrow Fixity) \rightarrow (Int \rightarrow Int) \rightarrow OpDecl \rightarrow OpDecl}
\]

update operator declaration

\[
\text{updOpName :: ((String,String) \rightarrow (String,String)) \rightarrow OpDecl \rightarrow OpDecl}
\]

update name of operator declaration

\[
\text{updOpFixity :: (Fixity \rightarrow Fixity) \rightarrow OpDecl \rightarrow OpDecl}
\]

update fixity of operator declaration

\[
\text{updOpPrecedence :: (Int \rightarrow Int) \rightarrow OpDecl \rightarrow OpDecl}
\]

update precedence of operator declaration

\[
\text{trFunc :: ((String,String) \rightarrow Int \rightarrow Visibility \rightarrow TypeExpr \rightarrow ARule a \rightarrow b) \rightarrow AFuncDecl a \rightarrow b}
\]

transform function

\[
\text{funcName :: AFuncDecl a \rightarrow (String,String)}
\]

get name of function

\[
\text{funcArity :: AFuncDecl a \rightarrow Int}
\]

get arity of function

\[
\text{funcVisibility :: AFuncDecl a \rightarrow Visibility}
\]
get visibility of function

funcType :: AFuncDecl a → TypeExpr

gtype type of function

funcRule :: AFuncDecl a → ARule a

gget rule of function

updFunc :: ((String,String) → (String,String)) → (Int → Int) → (Visibility → Visibility) → (TypeExpr → TypeExpr) → (ARule a → ARule a) → AFuncDecl a → AFuncDecl a

update function

updFuncName :: ((String,String) → (String,String)) → AFuncDecl a → AFuncDecl a

update name of function

updFuncArity :: (Int → Int) → AFuncDecl a → AFuncDecl a

update arity of function

updFuncVisibility :: (Visibility → Visibility) → AFuncDecl a → AFuncDecl a

update visibility of function

updFuncType :: (TypeExpr → TypeExpr) → AFuncDecl a → AFuncDecl a

update type of function

updFuncRule :: (ARule a → ARule a) → AFuncDecl a → AFuncDecl a

update rule of function

isExternal :: AFuncDecl a → Bool

is function externally defined?

allVarsInFunc :: AFuncDecl a → [Int]

gget variable names in a function declaration

funcArgs :: AFuncDecl a → [(Int,a)]

get arguments of function, if not externally defined

funcBody :: AFuncDecl a → AExpr a

get body of function, if not externally defined

funcRHS :: AFuncDecl a → [AExpr a]
rmnAllVarsInFunc :: (Int → Int) → AFuncDecl a → AFuncDecl a
    rename all variables in function

updQNamesInFunc :: ((String,String) → (String,String)) → AFuncDecl a → AFuncDecl a
    update all qualified names in function

updFuncArgs :: ([Int,a] → [Int,a]) → AFuncDecl a → AFuncDecl a
    update arguments of function, if not externally defined

updFuncBody :: (AExpr a → AExpr a) → AFuncDecl a → AFuncDecl a
    update body of function, if not externally defined

trRule :: (a → [(Int,a)] → AExpr a → b) → (a → String → b) → ARule a → b
    transform rule

ruleArgs :: ARule a → [(Int,a)]
    get rules arguments if it’s not external

ruleBody :: ARule a → AExpr a
    get rules body if it’s not external

ruleExtDecl :: ARule a → String
    get rules external declaration

isRuleExternal :: ARule a → Bool
    is rule external?

updRule :: (a → a) → ([Int,a] → [Int,a]) → (AExpr a → AExpr a) → (String → String) → ARule a → ARule a
    update rule

updRuleArgs :: ([Int,a] → [Int,a]) → ARule a → ARule a
    update rules arguments

updRuleBody :: (AExpr a → AExpr a) → ARule a → ARule a
    update rules body

updRuleExtDecl :: (String → String) → ARule a → ARule a
    update rules external declaration

allVarsInRule :: ARule a → [Int]
get variable names in a functions rule

```haskell
rmnAllVarsInRule :: (Int → Int) → ARule a → ARule a
```

rename all variables in rule

```haskell
updQNamesInRule :: ((String,String) → (String,String)) → ARule a → ARule a
```

update all qualified names in rule

```haskell
trCombType :: a → (Int → a) → a → (Int → a) → CombType → a
```

transform combination type

```haskell
isCombTypeFuncCall :: CombType → Bool
```

is type of combination FuncCall?

```haskell
isCombTypeFuncPartCall :: CombType → Bool
```

is type of combination FuncPartCall?

```haskell
isCombTypeConsCall :: CombType → Bool
```

is type of combination ConsCall?

```haskell
isCombTypeConsPartCall :: CombType → Bool
```

is type of combination ConsPartCall?

```haskell
missingArgs :: CombType → Int
```

get internal number of variable

```haskell
varNr :: AExpr a → Int
```

get literal if expression is literal expression

```haskell
literal :: AExpr a → Literal
```

get combination type of a combined expression

```haskell
combType :: AExpr a → CombType
```

get name of a combined expression

```haskell
combName :: AExpr a → (String,String)
```

get arguments of a combined expression

```haskell
combArgs :: AExpr a → [AExpr a]
```

get arguments of a combined expression

```haskell
missingCombArgs :: AExpr a → Int
```

238
get number of missing arguments if expression is combined

```haskell
letBinds :: AExpr a →[((Int,a),AExpr a)]
```

get indices of variables in let declaration

```haskell
letBody :: AExpr a → AExpr a
```

get body of let declaration

```haskell
freeVars :: AExpr a → [Int]
```

get variable indices from declaration of free variables

```haskell
freeExpr :: AExpr a → AExpr a
```

get expression from declaration of free variables

```haskell
orExps :: AExpr a → [AExpr a]
```

get expressions from or-expression

```haskell
caseType :: AExpr a → CaseType
```

get case-type of case expression

```haskell
caseExpr :: AExpr a → AExpr a
```

get scrutinee of case expression

```haskell
caseBranches :: AExpr a → [ABranchExpr a]
```

isVar :: AExpr a → Bool

is expression a variable?

```haskell
isLit :: AExpr a → Bool
```

is expression a literal expression?

```haskell
isComb :: AExpr a → Bool
```

is expression combined?

```haskell
isLet :: AExpr a → Bool
```

is expression a let expression?

```haskell
isFree :: AExpr a → Bool
```

is expression a declaration of free variables?

```haskell
isOr :: AExpr a → Bool
```
is expression an or-expression?

isCase :: AExpr a → Bool

is expression a case expression?

trExpr :: (a → Int → b) → (a → Literal → b) → (a → CombType →
((String, String), a) → [b] → b) → (a → (((Int, a), b) → b → b) → (a →
[(Int, a)] → b → b) → (a → b → b → b) → (a → CaseType → b → [c] → b)
→ (APattern a → b → c) → (a → b → TypeExpr → b) → AExpr a → b

transform expression

updVars :: (a → Int → AExpr a) → AExpr a → AExpr a

update all variables in given expression

updLiterals :: (a → Literal → AExpr a) → AExpr a → AExpr a

update all literals in given expression

updCombs :: (a → CombType → ((String, String), a) → [AExpr a] → AExpr a) →
AExpr a → AExpr a

update all combined expressions in given expression

updLets :: (a → [((Int, a), AExpr a)] → AExpr a → AExpr a) → AExpr a → AExpr a

update all let expressions in given expression

updFrees :: (a → [(Int, a)] → AExpr a → AExpr a) → AExpr a → AExpr a

update all free declarations in given expression

updOrs :: (a → AExpr a → AExpr a → AExpr a) → AExpr a → AExpr a

update all or expressions in given expression

updCases :: (a → CaseType → AExpr a → [ABranchExpr a] → AExpr a) → AExpr a →
AExpr a

update all case expressions in given expression

updBranches :: (APattern a → AExpr a → ABranchExpr a) → AExpr a → AExpr a

update all case branches in given expression

updTypeds :: (a → AExpr a → TypeExpr → AExpr a) → AExpr a → AExpr a

update all typed expressions in given expression

isFuncCall :: AExpr a → Bool

is expression a call of a function where all arguments are provided?
isFuncPartCall :: AExpr a → Bool
is expression a partial function call?

isConsCall :: AExpr a → Bool
is expression a call of a constructor?

isConsPartCall :: AExpr a → Bool
is expression a partial constructor call?

isGround :: AExpr a → Bool
is expression fully evaluated?

allVars :: AExpr a → [Int]
get all variables (also pattern variables) in expression

rnmAllVars :: (Int → Int) → AExpr a → AExpr a
rename all variables (also in patterns) in expression

updQNames :: ((String,String) → (String,String)) → AExpr a → AExpr a
update all qualified names in expression

trBranch :: (APattern a → AExpr a → b) → ABranchExpr a → b
transform branch expression

branchPattern :: ABranchExpr a → APattern a
get pattern from branch expression

branchExpr :: ABranchExpr a → AExpr a
get expression from branch expression

updBranch :: (APattern a → APattern a) → (AExpr a → AExpr a) → ABranchExpr a → ABranchExpr a
update branch expression

updBranchPattern :: (APattern a → APattern a) → ABranchExpr a → ABranchExpr a
update pattern of branch expression

updBranchExpr :: (AExpr a → AExpr a) → ABranchExpr a → ABranchExpr a
update expression of branch expression

trPattern :: (a → ((String,String),a) → [(Int,a)] → b) → (a → Literal → b) → APattern a → b
transform pattern

patCons :: APattern a → (String,String)

get name from constructor pattern

patArgs :: APattern a → [(Int,a)]

get arguments from constructor pattern

patLiteral :: APattern a → Literal

get literal from literal pattern

isConsPattern :: APattern a → Bool

is pattern a constructor pattern?

updPattern :: (((String,String),a) → ((String,String),a)) →
[(Int,a)] →
[(Int,a)]) → (Literal → Literal) → APattern a → APattern a

update pattern

updPatCons :: ((String,String) → (String,String)) → APattern a → APattern a

update constructors name of pattern

updPatArgs :: ([(Int,a)] → [(Int,a)]) → APattern a → APattern a

update arguments of constructor pattern

updPatLiteral :: (Literal → Literal) → APattern a → APattern a

update literal of pattern

patExpr :: APattern a → AExpr a

build expression from pattern

annRule :: ARule a → a

annExpr :: AExpr a → a

Extract the annotation of an annotated expression.

annPattern :: APattern a → a

Extract the annotation of an annotated pattern.

unAnnProg :: AProg a → Prog

unAnnFuncDecl :: AFuncDecl a → FuncDecl
unAnnRule :: ARule a → Rule

unAnnExpr :: AExpr a → Expr

unAnnPattern :: APattern a → Pattern

A.5.6 Library CompactFlatCurry

This module contains functions to reduce the size of FlatCurry programs by combining the main module and all imports into a single program that contains only the functions directly or indirectly called from a set of main functions.

Exported types:

data Option

   Options to guide the compactification process.

Exported constructors:

   • Verbose :: Option
     Verbose
     – for more output

   • Main :: String → Option
     Main
     – optimize for one main (unqualified!) function supplied here

   • Exports :: Option
     Exports
     – optimize w.r.t. the exported functions of the module only

   • InitFuncs :: [(String,String)] → Option
     InitFuncs
     – optimize w.r.t. given list of initially required functions

   • Required :: [RequiredSpec] → Option
     Required
- list of functions that are implicitly required and, thus, should not be deleted if the corresponding module is imported

- Import :: String → Option
  Import
  - module that should always be imported (useful in combination with option InitFuncs)

data RequiredSpec

  Data type to specify requirements of functions.

  Exported constructors:

  Exported functions:

  requires :: (String,String) → (String,String) → RequiredSpec

  (fun requires reqfun) specifies that the use of the function ”fun” implies the application of function ”reqfun”.

  alwaysRequired :: (String,String) → RequiredSpec

  (alwaysRequired fun) specifies that the function ”fun” should be always present if the corresponding module is loaded.

  defaultRequired :: [RequiredSpec]

  Functions that are implicitly required in a FlatCurry program (since they might be generated by external functions like ”==” or ”=:=” on the fly).

  generateCompactFlatCurryFile :: [Option] → String → String → IO ()

  Computes a single FlatCurry program containing all functions potentially called from a set of main functions and writes it into a FlatCurry file. This is done by merging all imported FlatCurry modules and removing the imported functions that are definitely not used.

  computeCompactFlatCurry :: [Option] → String → IO Prog

  Computes a single FlatCurry program containing all functions potentially called from a set of main functions. This is done by merging all imported FlatCurry modules (these are loaded demand-driven so that modules that contains no potentially called functions are not loaded) and removing the imported functions that are definitely not used.
A.5.7 Library CurryStringClassifier

The Curry string classifier is a simple tool to process strings containing Curry source code. The source string is classified into the following categories:

- **moduleHead** - module interface, imports, operators
- **code** - the part where the actual program is defined
- **big comment** - parts enclosed in \{ ... \}
- **small comment** - from ”–” to the end of a line
- **text** - a string, i.e. text enclosed in ”...”
- **letter** - the given string is the representation of a character
- **meta** - containing information for meta programming

For an example to use the state scanner cf. addtypes, the tool to add function types to a given program.

**Exported types:**

```
type Tokens = [Token]
data Token
```

The different categories to classify the source code.

**Exported constructors:**

- **SmallComment :: String → Token**
- **BigComment :: String → Token**
- **Text :: String → Token**
- **Letter :: String → Token**
- **Code :: String → Token**
- **ModuleHead :: String → Token**
- **Meta :: String → Token**
Exported functions:

isSmallComment :: Token → Bool
  test for category "SmallComment"

isBigComment :: Token → Bool
  test for category "BigComment"

isComment :: Token → Bool
  test if given token is a comment (big or small)

isText :: Token → Bool
  test for category "Text" (String)

isLetter :: Token → Bool
  test for category "Letter" (Char)

isCode :: Token → Bool
  test for category "Code"

isModuleHead :: Token → Bool
  test for category "ModuleHead", ie imports and operator declarations

isMeta :: Token → Bool
  test for category "Meta", ie between {+ and +}

scan :: String → [Token]
  Divides the given string into the six categories. For applications it is important to
  know whether a given part of code is at the beginning of a line or in the middle. The
  state scanner organizes the code in such a way that every string categorized as "Code"
  always starts in the middle of a line.

plainCode :: [Token] → String
  Yields the program code without comments (but with the line breaks for small com-
  ments).

unscan :: [Token] → String
  Inverse function of scan, i.e., unscan (scan x) = x. unscan is used to yield a program
  after changing the list of tokens.

readScan :: String → IO [Token]
  return tokens for given filename

testScan :: String → IO ()
  test whether (unscan . scan) is identity
Library FlatCurry

Library to support meta-programming in Curry.
This library contains a definition for representing FlatCurry programs in Curry (type "Prog") and an I/O action to read Curry programs and transform them into this representation (function "readFlatCurry").

Exported types:

- **type QName = (String,String)**
  - The data type for representing qualified names. In FlatCurry all names are qualified to avoid name clashes. The first component is the module name and the second component the unqualified name as it occurs in the source program.

- **type TVarIndex = Int**
  - The data type for representing type variables. They are represented by (TVar i) where i is a type variable index.

- **type VarIndex = Int**
  - Data type for representing object variables. Object variables occurring in expressions are represented by (Var i) where i is a variable index.

- **data Prog**
  - Data type for representing a Curry module in the intermediate form. A value of this data type has the form

    (Prog modname imports typedecls functions opdecls)

    where modname is the name of this module, imports is the list of modules names that are imported, and typedecls, functions, and opdecls are the list of data type, function, and operator declarations contained in this module, respectively.

*Exported constructors:*

- Prog :: String → [String] → [TypeDecl] → [FuncDecl] → [OpDecl] → Prog

- **data Visibility**
  - Data type to specify the visibility of various entities.

*Exported constructors:*

- Public :: Visibility
- Private :: Visibility
data TypeDecl

Data type for representing definitions of algebraic data types and type synonyms.
A data type definition of the form

data t x1...xn = ...| c t1....tkc |...

is represented by the FlatCurry term

(Type t [i1,...,in] [...(Cons c kc [t1,...,tkc])...])

where each ij is the index of the type variable xj.
Note: the type variable indices are unique inside each type declaration and are usually
numbered from 0
Thus, a data type declaration consists of the name of the data type, a list of type
parameters and a list of constructor declarations.

Exported constructors:
- Type :: (String,String) → Visibility → [Int] → [ConsDecl] → TypeDecl
- TypeSyn :: (String,String) → Visibility → [Int] → TypeExpr → TypeDecl

data ConsDecl

A constructor declaration consists of the name and arity of the constructor and a list
of the argument types of the constructor.

Exported constructors:
- Cons :: (String,String) → Int → Visibility → [TypeExpr] → ConsDecl

data TypeExpr

Data type for type expressions. A type expression is either a type variable, a function
type, or a type constructor application.
Note: the names of the predefined type constructors are "Int", "Float", "Bool", "Char",
"IO", "Success", "()" (unit type), "(,...)" (tuple types), "[]" (list type)

Exported constructors:
- TVar :: Int → TypeExpr
- FuncType :: TypeExpr → TypeExpr → TypeExpr
- TCons :: (String,String) → [TypeExpr] → TypeExpr

data OpDecl
Data type for operator declarations. An operator declaration \texttt{fix p n} in Curry corresponds to the FlatCurry term \texttt{(Op n fix p)}.

\textit{Exported constructors:}

- \texttt{Op :: (String,String) \rightarrow Fixity \rightarrow Int \rightarrow OpDecl}

\texttt{data Fixity}

Data types for the different choices for the fixity of an operator.

\textit{Exported constructors:}

- \texttt{InfixOp :: Fixity}
- \texttt{InfixlOp :: Fixity}
- \texttt{InfixrOp :: Fixity}

\texttt{data FuncDecl}

Data type for representing function declarations.
A function declaration in FlatCurry is a term of the form

\texttt{(Func name k type (Rule [i1,...,ik] e))}

and represents the function \texttt{name} with definition

\texttt{name :: type}

\texttt{name x1...xk = e}

where each \texttt{i j} is the index of the variable \texttt{xj}.

Note: the variable indices are unique inside each function declaration and are usually numbered from \texttt{0}.

External functions are represented as

\texttt{(Func name arity type (External s))}

where \texttt{s} is the external name associated to this function.

Thus, a function declaration consists of the name, arity, type, and rule.

\textit{Exported constructors:}

- \texttt{Func :: (String,String) \rightarrow Int \rightarrow Visibility \rightarrow TypeExpr \rightarrow Rule \rightarrow FuncDecl}

\texttt{data Rule}
A rule is either a list of formal parameters together with an expression or an "External" tag.

Exported constructors:

- Rule :: [Int] \to Expr \to Rule
- External :: String \to Rule

data CaseType

Data type for classifying case expressions. Case expressions can be either flexible or rigid in Curry.

Exported constructors:

- Rigid :: CaseType
- Flex :: CaseType

data CombType

Data type for classifying combinations (i.e., a function/constructor applied to some arguments).

Exported constructors:

- FuncCall :: CombType
  FuncCall
  \quad a call to a function where all arguments are provided

- ConsCall :: CombType
  ConsCall
  \quad a call with a constructor at the top, all arguments are provided

- FuncPartCall :: Int \to CombType
  FuncPartCall
  \quad a partial call to a function (i.e., not all arguments are provided) where the parameter is the number of missing arguments

- ConsPartCall :: Int \to CombType
  ConsPartCall
  \quad a partial call to a constructor (i.e., not all arguments are provided) where the parameter is the number of missing arguments

data Expr
Data type for representing expressions.

Remarks:
if-then-else expressions are represented as function calls:

\[(\text{if } e_1 \text{ then } e_2 \text{ else } e_3)\]

is represented as

\[\text{(Comb FuncCall ("Prelude","if\_then\_else") \{e_1,e_2,e_3\})}\]

Higher-order applications are represented as calls to the (external) function apply. For instance, the rule

\[\text{app } f \, x = f \, x\]

is represented as

\[\text{(Rule \{0,1\} (Comb FuncCall ("Prelude","apply") \{Var 0, Var 1\}))}\]

A conditional rule is represented as a call to an external function cond where the first argument is the condition (a constraint). For instance, the rule

\[\text{equal2 } x \mid x=:=2 = \text{ success}\]

is represented as

\[\text{(Rule \{0\} (Comb FuncCall ("Prelude","cond")}
\[\text{[Comb FuncCall ("Prelude","=:") \{Var 0, Lit (Intc 2)\},}
\text{Comb FuncCall ("Prelude","success") \{\}}})\]

Exported constructors:

- **Var :: Int \to Expr**

  Var
  
  - variable (represented by unique index)

- **Lit :: Literal \to Expr**

  Lit
  
  - literal (Int/Float/Char constant)
• Comb :: CombType → (String,String) → [Expr] → Expr
  Comb
  – application \( (f \; e_1 \ldots \; e_n) \) of function/constructor \( f \) with \( n \leq \text{arity}(f) \)

• Let :: [(Int,Expr)] → Expr → Expr
  Let
  – introduction of local variables via (recursive) let declarations

• Free :: [Int] → Expr → Expr
  Free
  – introduction of free local variables

• Or :: Expr → Expr → Expr
  Or
  – disjunction of two expressions (used to translate rules with overlapping left-hand sides)

• Case :: CaseType → Expr → [BranchExpr] → Expr
  Case
  – case distinction (rigid or flex)

• Typed :: Expr → TypeExpr → Expr
  Typed
  – typed expression to represent an expression with a type declaration

\textbf{data BranchExpr}

Data type for representing branches in a case expression.
Branches "\((m.c \; x_1\ldots x_n) \rightarrow e\)" in case expressions are represented as

\((\text{Branch} \; (\text{Pattern} \; (m, c) \; [i_1, \ldots, i_n]) \; e)\)

where each \( i_j \) is the index of the pattern variable \( x_j \), or as

\((\text{Branch} \; (\text{LPattern} \; (\text{Intc} \; i)) \; e)\)

for integers as branch patterns (similarly for other literals like float or character constants).

\textit{Exported constructors:}

• Branch :: Pattern → Expr → BranchExpr
data Pattern

Data type for representing patterns in case expressions.

Exported constructors:

- Pattern :: (String,String) \rightarrow [Int] \rightarrow Pattern
- LPattern :: Literal \rightarrow Pattern

data Literal

Data type for representing literals occurring in an expression or case branch. It is either an integer, a float, or a character constant.

Exported constructors:

- Intc :: Int \rightarrow Literal
- Floatc :: Float \rightarrow Literal
- Charc :: Char \rightarrow Literal

Exported functions:

readFlatCurry :: String \rightarrow IO Prog

I/O action which parses a Curry program and returns the corresponding FlatCurry program. Thus, the argument is the module path (without suffix ".curry" or ".lcurry") and the result is a FlatCurry term representing this program.

readFlatCurryWithParseOptions :: String \rightarrow FrontendParams \rightarrow IO Prog

I/O action which parses a Curry program with respect to some parser options and returns the corresponding FlatCurry program. This I/O action is used by the standard action readFlatCurry.

flatCurryFileName :: String \rightarrow String

Transforms a name of a Curry program (with or without suffix ".curry" or ".lcurry") into the name of the file containing the corresponding FlatCurry program.

flatCurryIntName :: String \rightarrow String

Transforms a name of a Curry program (with or without suffix ".curry" or ".lcurry") into the name of the file containing the corresponding FlatCurry program.

readFlatCurryFile :: String \rightarrow IO Prog

I/O action which reads a FlatCurry program from a file in ".fcy" format. In contrast to readFlatCurry, this action does not parse a source program. Thus, the argument must be the name of an existing file (with suffix ".fcy") containing a FlatCurry program in ".fcy" format and the result is a FlatCurry term representing this program.
readFlatCurryInt :: String → IO Prog

I/O action which returns the interface of a Curry module, i.e., a FlatCurry program containing only "Public" entities and function definitions without rules (i.e., external functions). The argument is the file name without suffix ".curry" (or ".lcurry") and the result is a FlatCurry term representing the interface of this module.

writeFCY :: String → Prog → IO ()

Writes a FlatCurry program into a file in ".fcy" format. The first argument must be the name of the target file (with suffix ".fcy").

showQNameInModule :: String → (String,String) → String

Translates a given qualified type name into external name relative to a module. Thus, names not defined in this module (except for names defined in the prelude) are prefixed with their module name.

A.5.9 Library FlatCurryGoodies

This library provides selector functions, test and update operations as well as some useful auxiliary functions for FlatCurry data terms. Most of the provided functions are based on general transformation functions that replace constructors with user-defined functions. For recursive datatypes the transformations are defined inductively over the term structure. This is quite usual for transformations on FlatCurry terms, so the provided functions can be used to implement specific transformations without having to explicitly state the recursion. Essentially, the tedious part of such transformations - descend in fairly complex term structures - is abstracted away, which hopefully makes the code more clear and brief.

Exported types:

type Update a b = (b → b) → a → a

Exported functions:

trProg :: (String → [String] → [TypeDecl] → [FuncDecl] → [OpDecl] → a) → Prog → a

transform program

progName :: Prog → String

get name from program

progImports :: Prog → [String]

get imports from program

progTypes :: Prog → [TypeDecl]
get type declarations from program

\[
\text{progFuncs} :: \text{Prog} \rightarrow \text{[FuncDecl]}
\]

get functions from program

\[
\text{progOps} :: \text{Prog} \rightarrow \text{[OpDecl]}
\]

get infix operators from program

\[
\text{updProg} :: (\text{String} \rightarrow \text{String}) \rightarrow (\text{[String]} \rightarrow \text{[String]}) \rightarrow (\text{[TypeDecl]} \rightarrow \\
\text{[TypeDecl]}) \rightarrow (\text{[FuncDecl]} \rightarrow \text{[FuncDecl]}) \rightarrow (\text{[OpDecl]} \rightarrow \text{[OpDecl]}) \rightarrow \text{Prog} \rightarrow \\
\text{Prog}
\]

update program

\[
\text{updProgName} :: (\text{String} \rightarrow \text{String}) \rightarrow \text{Prog} \rightarrow \text{Prog}
\]

update name of program

\[
\text{updProgImports} :: (\text{[String]} \rightarrow \text{[String]}) \rightarrow \text{Prog} \rightarrow \text{Prog}
\]

update imports of program

\[
\text{updProgTypes} :: (\text{[TypeDecl]} \rightarrow \text{[TypeDecl]}) \rightarrow \text{Prog} \rightarrow \text{Prog}
\]

update type declarations of program

\[
\text{updProgFuncs} :: (\text{[FuncDecl]} \rightarrow \text{[FuncDecl]}) \rightarrow \text{Prog} \rightarrow \text{Prog}
\]

update functions of program

\[
\text{updProgOps} :: (\text{[OpDecl]} \rightarrow \text{[OpDecl]}) \rightarrow \text{Prog} \rightarrow \text{Prog}
\]

update infix operators of program

\[
\text{allVarsInProg} :: \text{Prog} \rightarrow \text{[Int]}
\]

get all program variables (also from patterns)

\[
\text{updProgExps} :: (\text{Expr} \rightarrow \text{Expr}) \rightarrow \text{Prog} \rightarrow \text{Prog}
\]

lift transformation on expressions to program

\[
\text{rnmAllVarsInProg} :: (\text{Int} \rightarrow \text{Int}) \rightarrow \text{Prog} \rightarrow \text{Prog}
\]

rename programs variables

\[
\text{updQNamesInProg} :: ((\text{String},\text{String}) \rightarrow (\text{String},\text{String})) \rightarrow \text{Prog} \rightarrow \text{Prog}
\]

update all qualified names in program

\[
\text{rnmProg} :: \text{String} \rightarrow \text{Prog} \rightarrow \text{Prog}
\]

rename program (update name of and all qualified names in program)
trType :: ((String,String) → Visibility → [Int] → [ConsDecl] → a) →
((String,String) → Visibility → [Int] → TypeExpr → a) → TypeDecl → a

transform type declaration

typeName :: TypeDecl → (String,String)

generate name of type declaration

typeVisibility :: TypeDecl → Visibility

generate visibility of type declaration

typeParams :: TypeDecl → [Int]

generate type parameters of type declaration

typeConsDecls :: TypeDecl → [ConsDecl]

generate constructor declarations from type declaration

getTypeSyn :: TypeDecl → TypeExpr

generate synonym of type declaration

isTypeSyn :: TypeDecl → Bool

is type declaration a type synonym?

updType :: ((String,String) → (String,String)) → (Visibility → Visibility)
→ ([Int] → [Int]) → ([ConsDecl] → [ConsDecl]) → (TypeExpr → TypeExpr) →
TypeDecl → TypeDecl

update type declaration

updtypeName :: ((String,String) → (String,String)) → TypeDecl → TypeDecl

update name of type declaration

updTypeVisibility :: (Visibility → Visibility) → TypeDecl → TypeDecl

update visibility of type declaration

updTypeParams :: ([Int] → [Int]) → TypeDecl → TypeDecl

update type parameters of type declaration

updTypeConsDecls :: ([ConsDecl] → [ConsDecl]) → TypeDecl → TypeDecl

update constructor declarations of type declaration

updTypeSynonym :: (TypeExpr → TypeExpr) → TypeDecl → TypeDecl

update synonym of type declaration
updQNamesInType :: ((String,String) → (String,String)) → TypeDecl → TypeDecl
    update all qualified names in type declaration

trCons :: ((String,String) → Int → Visibility → [TypeExpr] → a) → ConsDecl → a
    transform constructor declaration

consName :: ConsDecl → (String,String)
    get name of constructor declaration

consArity :: ConsDecl → Int
    get arity of constructor declaration

consVisibility :: ConsDecl → Visibility
    get visibility of constructor declaration

consArgs :: ConsDecl → [TypeExpr]
    get arguments of constructor declaration

updCons :: ((String,String) → (String,String)) → (Int → Int) → (Visibility → Visibility) → ([TypeExpr] → [TypeExpr]) → ConsDecl → ConsDecl
    update constructor declaration

updConsName :: ((String,String) → (String,String)) → ConsDecl → ConsDecl
    update name of constructor declaration

updConsArity :: (Int → Int) → ConsDecl → ConsDecl
    update arity of constructor declaration

updConsVisibility :: (Visibility → Visibility) → ConsDecl → ConsDecl
    update visibility of constructor declaration

updConsArgs :: ([TypeExpr] → [TypeExpr]) → ConsDecl → ConsDecl
    update arguments of constructor declaration

updQNamesInConsDecl :: ((String,String) → (String,String)) → ConsDecl → ConsDecl
    update all qualified names in constructor declaration

tVarIndex :: TypeExpr → Int
    get index from type variable
domain :: TypeExpr → TypeExpr
  get domain from functional type
range :: TypeExpr → TypeExpr
  get range from functional type
tConsName :: TypeExpr → (String,String)
  get name from constructed type
tConsArgs :: TypeExpr → [TypeExpr]
  get arguments from constructed type
trTypeExpr :: (Int → a) → ((String,String) → [a] → a) → (a → a → a) → TypeExpr → a
  transform type expression
isTVar :: TypeExpr → Bool
  is type expression a type variable?
isTCons :: TypeExpr → Bool
  is type declaration a constructed type?
isFuncType :: TypeExpr → Bool
  is type declaration a functional type?
updTVars :: (Int → TypeExpr) → TypeExpr → TypeExpr
  update all type variables
updTCons :: ((String,String) → [TypeExpr] → TypeExpr) → TypeExpr → TypeExpr
  update all type constructors
updFuncTypes :: (TypeExpr → TypeExpr → TypeExpr) → TypeExpr → TypeExpr
  update all functional types
argTypes :: TypeExpr → [TypeExpr]
  get argument types from functional type
resultType :: TypeExpr → TypeExpr
  get result type from (nested) functional type
rnmAllVarsInTypeExpr :: (Int → Int) → TypeExpr → TypeExpr
  rename variables in type expression
updQNamesInTypeExpr :: ((String,String) → (String,String)) → TypeExpr → TypeExpr
update all qualified names in type expression

trOp :: ((String,String) → Fixity → Int → a) → OpDecl → a
transform operator declaration

opName :: OpDecl → (String,String)
get name from operator declaration

opFixity :: OpDecl → Fixity
get fixity of operator declaration

opPrecedence :: OpDecl → Int
get precedence of operator declaration

updOp :: ((String,String) → (String,String)) → (Fixity → Fixity) → (Int → Int) → OpDecl → OpDecl
update operator declaration

updOpName :: ((String,String) → (String,String)) → OpDecl → OpDecl
update name of operator declaration

updOpFixity :: (Fixity → Fixity) → OpDecl → OpDecl
update fixity of operator declaration

updOpPrecedence :: (Int → Int) → OpDecl → OpDecl
update precedence of operator declaration

trFunc :: ((String,String) → Int → Visibility → TypeExpr → Rule → a) → FuncDecl → a
transform function

funcName :: FuncDecl → (String,String)
get name of function

funcArity :: FuncDecl → Int
get arity of function

funcVisibility :: FuncDecl → Visibility
get visibility of function
funcType :: FuncDecl → TypeExpr
    get type of function

funcRule :: FuncDecl → Rule
    get rule of function

updFunc :: ((String,String) → (String,String)) → (Int → Int) → (Visibility → Visibility) → (TypeExpr → TypeExpr) → (Rule → Rule) → FuncDecl → FuncDecl
    update function

updFuncName :: ((String,String) → (String,String)) → FuncDecl → FuncDecl
    update name of function

updFuncArity :: (Int → Int) → FuncDecl → FuncDecl
    update arity of function

updFuncVisibility :: (Visibility → Visibility) → FuncDecl → FuncDecl
    update visibility of function

updFuncType :: (TypeExpr → TypeExpr) → FuncDecl → FuncDecl
    update type of function

updFuncRule :: (Rule → Rule) → FuncDecl → FuncDecl
    update rule of function

isExternal :: FuncDecl → Bool
    is function externally defined?

allVarsInFunc :: FuncDecl → [Int]
    get variable names in a function declaration

funcArgs :: FuncDecl → [Int]
    get arguments of function, if not externally defined

funcBody :: FuncDecl → Expr
    get body of function, if not externally defined

funcRHS :: FuncDecl → [Expr]

rnmAllVarsInFunc :: (Int → Int) → FuncDecl → FuncDecl
    rename all variables in function
updQNamesInFunc :: ((String, String) → (String, String)) → FuncDecl → FuncDecl
  update all qualified names in function
updFuncArgs :: ([Int] → [Int]) → FuncDecl → FuncDecl
  update arguments of function, if not externally defined
updFuncBody :: (Expr → Expr) → FuncDecl → FuncDecl
  update body of function, if not externally defined
trRule :: ([Int] → Expr → a) → (String → a) → Rule → a
  transform rule
ruleArgs :: Rule → [Int]
  get rules arguments if it’s not external
ruleBody :: Rule → Expr
  get rules body if it’s not external
ruleExtDecl :: Rule → String
  get rules external declaration
isRuleExternal :: Rule → Bool
  is rule external?
updRule :: ([Int] → [Int]) → (Expr → Expr) → (String → String) → Rule → Rule
  update rule
updRuleArgs :: ([Int] → [Int]) → Rule → Rule
  update rules arguments
updRuleBody :: (Expr → Expr) → Rule → Rule
  update rules body
updRuleExtDecl :: (String → String) → Rule → Rule
  update rules external declaration
allVarsInRule :: Rule → [Int]
  get variable names in a functions rule
rnmAllVarsInRule :: (Int → Int) → Rule → Rule
  rename all variables in rule
updQNamesInRule :: ((String, String) → (String, String)) → Rule → Rule

update all qualified names in rule

trCombType :: a → (Int → a) → a → (Int → a) → CombType → a

transform combination type

isCombTypeFuncCall :: CombType → Bool

is type of combination FuncCall?

isCombTypeFuncPartCall :: CombType → Bool

is type of combination FuncPartCall?

isCombTypeConsCall :: CombType → Bool

is type of combination ConsCall?

isCombTypeConsPartCall :: CombType → Bool

is type of combination ConsPartCall?

missingArgs :: CombType → Int

varNr :: Expr → Int

get internal number of variable

literal :: Expr → Literal

generate literal if expression is literal expression

combType :: Expr → CombType

get combination type of a combined expression

combName :: Expr → (String, String)

get name of a combined expression

combArgs :: Expr → [Expr]

get arguments of a combined expression

missingCombArgs :: Expr → Int

get number of missing arguments if expression is combined

letBinds :: Expr → [(Int, Expr)]

get indices of variables in let declaration
letBody :: Expr → Expr
get body of let declaration

freeVars :: Expr → [Int]
get variable indices from declaration of free variables

freeExpr :: Expr → Expr
get expression from declaration of free variables

orExps :: Expr → [Expr]
get expressions from or-expression

caseType :: Expr → CaseType
get case-type of case expression

caseExpr :: Expr → Expr
get scrutinee of case expression

caseBranches :: Expr → [BranchExpr]
get branch expressions from case expression

isVar :: Expr → Bool
is expression a variable?

isLit :: Expr → Bool
is expression a literal expression?

isComb :: Expr → Bool
is expression combined?

isLet :: Expr → Bool
is expression a let expression?

isFree :: Expr → Bool
is expression a declaration of free variables?

isOr :: Expr → Bool
is expression an or-expression?

isCase :: Expr → Bool
is expression a case expression?
trExpr :: (Int → a) → (Literal → a) → (CombType → (String,String) → [a] → a) → ([(Int,a)] → a → a) → ([Int] → a → a) → (a → a → a) → (CaseType → a → [b] → a) → (Pattern → a → b) → (a → TypeExpr → a) → Expr → a

transform expression

updVars :: (Int → Expr) → Expr → Expr
update all variables in given expression

updLiterals :: (Literal → Expr) → Expr → Expr
update all literals in given expression

updCombs :: (CombType → (String,String) → [Expr] → Expr) → Expr → Expr
update all combined expressions in given expression

updLets :: ([((Int,Expr)] → Expr → Expr) → Expr → Expr
update all let expressions in given expression

updFrees :: ([Int] → Expr → Expr) → Expr → Expr
update all free declarations in given expression

updOrs :: (Expr → Expr → Expr) → Expr → Expr
update all or expressions in given expression

updCases :: (CaseType → Expr → [BranchExpr] → Expr) → Expr → Expr
update all case expressions in given expression

updBranches :: (Pattern → Expr → BranchExpr) → Expr → Expr
update all case branches in given expression

updTypeds :: (Expr → TypeExpr → Expr) → Expr → Expr
update all typed expressions in given expression

isFuncCall :: Expr → Bool
is expression a call of a function where all arguments are provided?

isFuncPartCall :: Expr → Bool
is expression a partial function call?

isConsCall :: Expr → Bool
is expression a call of a constructor?

isConsPartCall :: Expr → Bool
is expression a partial constructor call?

\textbf{isGround :: Expr \to Bool}

is expression fully evaluated?

\textbf{allVars :: Expr \to [Int]}

get all variables (also pattern variables) in expression

\textbf{rnmAllVars :: (Int \to Int) \to Expr \to Expr}

rename all variables (also in patterns) in expression

\textbf{updQNames :: ((String,String) \to (String,String)) \to Expr \to Expr}

update all qualified names in expression

\textbf{trBranch :: (Pattern \to Expr \to a) \to BranchExpr \to a}

transform branch expression

\textbf{branchPattern :: BranchExpr \to Pattern}

get pattern from branch expression

\textbf{branchExpr :: BranchExpr \to Expr}

get expression from branch expression

\textbf{updBranch :: (Pattern \to Pattern) \to (Expr \to Expr) \to BranchExpr \to BranchExpr}

update branch expression

\textbf{updBranchPattern :: (Pattern \to Pattern) \to BranchExpr \to BranchExpr}

update pattern of branch expression

\textbf{updBranchExpr :: (Expr \to Expr) \to BranchExpr \to BranchExpr}

update expression of branch expression

\textbf{trPattern :: ((String,String) \to [Int] \to a) \to (Literal \to a) \to Pattern \to a}

transform pattern

\textbf{patCons :: Pattern \to (String,String)}

get name from constructor pattern

\textbf{patArgs :: Pattern \to [Int]}

get arguments from constructor pattern

\textbf{patLiteral :: Pattern \to Literal}
get literal from literal pattern

isConsPattern :: Pattern → Bool

is pattern a constructor pattern?

updPattern :: ((String,String) → (String,String)) → ([Int] → [Int]) → (Literal → Literal) → Pattern → Pattern

update pattern

updPatCons :: ((String,String) → (String,String)) → Pattern → Pattern

update constructors name of pattern

updPatArgs :: ([Int] → [Int]) → Pattern → Pattern

update arguments of constructor pattern

updPatLiteral :: (Literal → Literal) → Pattern → Pattern

update literal of pattern

patExpr :: Pattern → Expr

build expression from pattern

A.5.10 Library FlatCurryRead

This library defines operations to read a FlatCurry programs or interfaces together with all its imported modules in the current load path.

Exported functions:

readFlatCurryWithImports :: String → IO [Prog]

Reads a FlatCurry program together with all its imported modules. The argument is the name of the main module (possibly with a directory prefix).

readFlatCurryWithImportsInPath :: [String] → String → IO [Prog]

Reads a FlatCurry program together with all its imported modules in a given load path. The arguments are a load path and the name of the main module.

readFlatCurryIntWithImports :: String → IO [Prog]

Reads a FlatCurry interface together with all its imported module interfaces. The argument is the name of the main module (possibly with a directory prefix). If there is no interface file but a FlatCurry file (suffix ".fcy"), the FlatCurry file is read instead of the interface.

readFlatCurryIntWithImportsInPath :: [String] → String → IO [Prog]

Reads a FlatCurry interface together with all its imported module interfaces in a given load path. The arguments are a load path and the name of the main module. If there is no interface file but a FlatCurry file (suffix ".fcy"), the FlatCurry file is read instead of the interface.
A.5.11 Library FlatCurryShow

Some tools to show FlatCurry programs. This library contains

- show functions for a string representation of FlatCurry programs (showFlatProg, showFlatType, showFlatFunc)
- functions for showing FlatCurry (type) expressions in (almost) Curry syntax (showCurryType, showCurryExpr, ...).

Exported functions:

showFlatProg :: Prog → String

Shows a FlatCurry program term as a string (with some pretty printing).

showFlatType :: TypeDecl → String

showFlatFunc :: FuncDecl → String

showCurryType :: ((String,String) → String) → Bool → TypeExpr → String

Shows a FlatCurry type in Curry syntax.

showCurryExpr :: ((String,String) → String) → Bool → Int → Expr → String

Shows a FlatCurry expressions in (almost) Curry syntax.

showCurryVar :: a → String

showCurryId :: String → String

Shows an identifier in Curry form. Thus, operators are enclosed in brackets.

A.5.12 Library FlatCurryXML

This library contains functions to convert FlatCurry programs into corresponding XML expressions and vice versa. This can be used to store Curry programs in a way independent from PAKCS or to use the PAKCS back end by other systems.
Exported functions:

flatCurry2XmlFile :: Prog → String → IO ()

Transforms a FlatCurry program term into a corresponding XML file.

flatCurry2Xml :: Prog → XmlExp

Transforms a FlatCurry program term into a corresponding XML expression.

xmlFile2FlatCurry :: String → IO Prog

Reads an XML file with a FlatCurry program and returns the FlatCurry program.

xml2FlatCurry :: XmlExp → Prog

Transforms an XML term into a FlatCurry program.

A.5.13 Library FlexRigid

This library provides a function to compute the rigid/flex status of a FlatCurry expression (right-hand side of a function definition).

Exported types:

data FlexRigidResult

Datatype for representing a flex/rigid status of an expression.

Exported constructors:

• UnknownFR :: FlexRigidResult
• ConflictFR :: FlexRigidResult
• KnownFlex :: FlexRigidResult
• KnownRigid :: FlexRigidResult

Exported functions:

getFlexRigid :: Expr → FlexRigidResult

Computes the rigid/flex status of a FlatCurry expression. This function checks all cases in this expression. If the expression has rigid as well as flex cases (which cannot be the case for source level programs but might occur after some program transformations), the result ConflictFR is returned.

A.5.14 Library PrettyAbstract

Library for pretty printing AbstractCurry programs. In contrast to the library AbstractCurryPrinter, this library implements a better human-readable pretty printing of AbstractCurry programs.
Exported functions:

preludePrecs :: [((String,String),(CFixity,Int))]
the precedences of the operators in the Prelude module

prettyCProg :: Int → CurryProg → String
(prettyCProg w prog) pretty prints the curry prog prog and fits it to a page width of w characters.

prettyCTypeExpr :: String → CTypeExpr → String
(prettyCTypeExpr mod typeExpr) pretty prints the type expression typeExpr of the module mod and fits it to a page width of 78 characters.

prettyCTypes :: String → [CTypeDecl] → String
(prettyCTypes mod typeDecls) pretty prints the type declarations typeDecls of the module mod and fits it to a page width of 78 characters.

prettyCOps :: [COpDecl] → String
(prettyCOps opDecls) pretty prints the operators opDecls and fits it to a page width of 78 characters.

showCProg :: CurryProg → String
(showCProg prog) pretty prints the curry prog prog and fits it to a page width of 78 characters.

cprogDoc :: CurryProg → Doc
(cprogDoc prog) creates a document of the Curry program prog and fits it to a page width of 78 characters.

cprogDocWithPrecedences :: [((String,String),(CFixity,Int))] → CurryProg → Doc
(cprogDocWithPrecedences prec prog) creates a document of the curry prog prog and fits it to a page width of 78 characters, the precedences prec ensure a correct bracketing of infix operators

precs :: [COpDecl] → [((String,String),(CFixity,Int))]
generates a list of precedences
B Markdown Syntax

This document describes the syntax of texts containing markdown elements. The markdown syntax is intended to simplify the writing of texts whose source is readable and can be easily formatted, e.g., as part of a web document. It is a subset of the original markdown syntax (basically, only internal links and pictures are missing) supported by the Curry library Markdown.

B.1 Paragraphs and Basic Formatting

Paragraphs are separated by at least one line which is empty or does contain only blanks.

Inside a paragraph, one can emphasize text or also strongly emphasize text. This is done by wrapping it with one or two _ or * characters:

_ emphasize_

*emphasize*

__strong__

**strong**

Furthermore, one can also mark program code text by backtick quotes (‘):

The function ‘fib’ computes Fibonacci numbers.

Web links can be put in angle brackets, like in the link http://www.google.com:

<http://www.google.com>

Currently, only links starting with 'http' are recognized (so that one can also use HTML markup). If one wants to put a link under a text, one can put the text in square brackets directly followed by the link in round brackets, as in Google:

[Google](http://www.google.com)

If one wants to put a character that has a specific meaning in the syntax of Markdown, like * or _, in the output document, it should be escaped with a backslash, i.e., a backslash followed by a special character in the source text is translated into the given character (this also holds for program code, see below). For instance, the input text

\_word\_

produces the output "_word_". The following backslash escapes are recognized:

\ backslash
‘ backtick
* asterisk
_ underscore
{} curly braces
[] square brackets
B.2 Lists and Block Formatting

An unordered list (i.e., without numbering) is introduced by putting a star in front of the list elements (where the star can be preceded by blanks). The individual list elements must contain the same indentation, as in

* First list element
  with two lines

* Next list element.

  It contains two paragraphs.

* Final list element.

This is formatted as follows:

- First list element with two lines
- Next list element.
  It contains two paragraphs.
- Final list element.

Instead of a star, one can also put dashes or plus to mark unordered list items. Furthermore, one could nest lists. Thus, the input text

- Color:
  + Yellow
  + Read
  + Blue
- BW:
  + Black
  + White

is formatted as

- Color:
Similarly, ordered lists (i.e., with numbering each item) are introduced by a number followed by a dot and at least one blank. All following lines belonging to the same numbered item must have the same indent as the first line. The actual value of the number is not important. Thus, the input

1. First element

99. Second element

is formatted as

1. First element

2. Second element

A quotation block is marked by putting a right angle followed by a blank in front of each line:

> This is
> a quotation.

It will be formatted as a quote element:

This is a quotation.

A block containing program code starts with a blank line and is marked by intending each input line by at least four spaces where all following lines must have at least the same indentation as the first non-blank character of the first line:

\[
f x y = \text{let } z = (x,y)\n\text{ in } (z,z)\]

The indentation is removed in the output:

\[
f x y = \text{let } z = (x,y)\n\text{ in } (z,z)\]

To visualize the structure of a document, one can also put a line containing only blanks and at least three dashes (stars would also work) in the source text:

--------------------------------------------------

This is formatted as a horizontal line:
B.3 Headers

The are two forms to mark headers. In the first form, one can "underline" the main header in the source text by equal signs and the second-level header by dashes:

First-level header
==================

Second-level header
-------------------

Alternatively (and for more levels), one can prefix the header line by up to six hash characters, where the number of characters corresponds to the header level (where level 1 is the main header):

# Main header

## Level 2 header

### Level 3

#### Level 4

##### Level 5

###### Level 6
C Overview of the PAKCS Distribution

A schematic overview of the various components contained in the distribution of PAKCS and the translation process of programs inside PAKCS is shown in Figure 3 on page 275. In this figure, boxes denote different components of PAKCS and names in boldface denote files containing various intermediate representations during the translation process (see Section D below). The PAKCS distribution contains a front end for reading (parsing and type checking) Curry programs that can be also used by other Curry implementations. The back end (formerly known as “Curry2Prolog”) compiles Curry programs into Prolog programs. It also support constraint solvers for arithmetic constraints over real numbers and finite domain constraints, and further libraries for GUI programming, meta-programming etc. Currently, it does not implement encapsulated search in full generality (only a strict version of \texttt{findall} is supported), and concurrent threads are not executed in a fair manner.
Figure 3: Overview of PAKCS
D Auxiliary Files

During the translation and execution of a Curry program with PAKCS, various intermediate representations of the source program are created and stored in different files which are shortly explained in this section. If you use PAKCS, it is not necessary to know about these auxiliary files because they are automatically generated and updated. You should only remember the command for deleting all auxiliary files ("cleancurry", see Section 1.1) to clean up your directories.

The various components of PAKCS create the following auxiliary files.

prog.fcy: This file contains the Curry program in the so-called “FlatCurry” representation where all functions are global (i.e., lambda lifting has been performed) and pattern matching is translated into explicit case/or expressions (compare Appendix A.1.4). This representation might be useful for other back ends and compilers for Curry and is the basis doing metaprogramming in Curry. This file is implicitly generated when a program is read by PAKCS. It can be also explicitly generated by the Curry front end

cymake --flat -ipakcs/home/lib -ipakcs/home/lib/meta prog

The FlatCurry representation of a Curry program is usually generated by the front-end after parsing, type checking and eliminating local declarations.

If the Curry module $M$ is stored in the directory $dir$, the corresponding FlatCurry program is stored in the directory “$dir/.curry”’. This is also the case for hierarchical module names: if the module $D1.D2.M$ is stored in the directory $dir$ (i.e., the module is actually stored in $dir/D1/D2/M.curry$), then the corresponding FlatCurry program is stored in “$dir/.curry/D1/D2/M.fcy$”.

prog.fint: This file contains the interface of the program in the so-called “FlatCurry” representation, i.e., it is similar to $prog.fcy$ but contains only exported entities and the bodies of all functions omitted (i.e., “external”). This representation is useful for providing a fast access to module interfaces. It can be also implicitly generated by the Curry front end

cymake --flat -ipakcs/home/lib -ipakcs/home/lib/meta prog

and stored in the same directory as $prog.fcy$.

prog.pl: This file contains a Prolog program as the result of translating the Curry program with PAKCS.

If the Curry module $M$ is stored in the directory $dir$, the corresponding Prolog program is stored in the directory “$dir/.curry/pakcs”’. This is also the case for hierarchical module names: if the module $D1.D2.M$ is stored in the directory $dir$ (i.e., the module is actually stored in $dir/D1/D2/M.curry$), then the corresponding Prolog program is stored in “$dir/.curry/pakcs/D1/D2/prog.pl$”.

prog.po: This file contains the Prolog program $prog.pl$ in an intermediate format for faster loading. This file is stored in the same directory as $prog.pl$.

prog: This file contains the executable after compiling and saving a program with PAKCS (see Section 2.2).
E External Functions

Currently, PAKCS has no general interface to external functions. Therefore, if a new external function should be added to the system, this function must be declared as \texttt{external} in the Curry source code and then an implementation for this external function must be inserted in the corresponding back end. An external function is defined as follows in the Curry source code:

1. Add a type declaration for the external function somewhere in the body of the appropriate file (usually, the prelude or some system module).

2. For external functions it is not allowed to define any rule since their semantics is determined by an external implementation. Instead of the defining rules, you have to write

   \begin{verbatim}
   f external
   \end{verbatim}

   somewhere in the file containing the type declaration for the external function \texttt{f}.

For instance, the addition on integers can be declared as an external function as follows:

\begin{verbatim}
(+) :: Int \to Int \to Int
(+) external
\end{verbatim}

The further modifications to be done for an inclusion of an external function has to be done in the back end. A new external function is added to the back end of PAKCS by informing the compiler about the existence of an external function and adding an implementation of this function in the run-time system. Therefore, the following items must be added in the PAKCS compiler system:

1. If the Curry module \texttt{Mod} contains external functions, there must be a file named \texttt{Mod.prim_c2p} containing the specification of these external functions. The contents of this file is in XML format and has the following general structure:\footnote{http://www.informatik.uni-kiel.de/~pakcs/primitives.dtd contains a DTD describing the exact structure of these files.}

   \begin{verbatim}
   <primitives>
   \hspace{1cm} specification of external function \texttt{f}_1 \\
   \hspace{1cm} ... \\
   \hspace{1cm} specification of external function \texttt{f}_n \\
   </primitives>
   \end{verbatim}

   The specification of an external function \texttt{f} with arity \texttt{n} has the form

   \begin{verbatim}
   <primitive name="f" arity="n">
   \hspace{1cm} <library>\texttt{lib}</library>
   \hspace{1cm} <entry>\texttt{pred}</entry>
   </primitive>
   \end{verbatim}

   where \texttt{lib} is the Prolog library (stored in the directory of the Curry module or in the global directory \texttt{pakcshome/curry2prolog/lib_src}) containing the code implementing this function and \texttt{pred} is a predicate name in this library implementing this function. Note that the function \texttt{f} must be declared in module \texttt{Mod}: either as an external function or defined in
Curry by equations. In the latter case, the Curry definition is not translated but calls to this function are redirected to the Prolog code specified above.

Furthermore, the list of specifications can also contain entries of the form

```xml
<ignore name="f" arity="n" />
```

for functions \( f \) with arity \( n \) that are declared in module \( \text{Mod} \) but should be ignored for code generation, e.g., since they are never called w.r.t. to the current implementation of external functions. For instance, this is useful when functions that can be defined in Curry should be (usually more efficiently) implemented as external functions.

Note that the arguments are passed in their current (possibly unevaluated) form. Thus, if the external function requires the arguments to be evaluated in a particular form, this must be done before calling the external function. For instance, the external function for adding two integers requires that both arguments must be evaluated to non-variable head normal form (which is identical to the ground constructor normal form). Therefore, the function “+” is specified in the prelude by

\[
(+) :: \text{Int} \to \text{Int} \to \text{Int} \\
x + y = (\text{prim}_{\text{Int}+} \# y) \# x
\]

where \( \text{prim}_{\text{Int}+} \) is the actual external function implementing the addition on integers. Consequently, the specification file \( \text{Prelude.prim_c2p} \) has an entry of the form

```xml
<primitive name="\text{prim}_{\text{Int}+}" arity="2">
  <library>\text{prim_standard}</library>
  <entry>\text{prim}_{\text{Int}+}</entry>
</primitive>
```

where the Prolog library \( \text{prim_standard.pl} \) contains the Prolog code implementing this function.

2. For most external functions, a **standard interface** is generated by the compiler so that an \( n \)-ary function can be implemented by an \( (n+1) \)-ary predicate where the last argument must be instantiated to the result of evaluating the function. The standard interface can be used if all arguments are ensured to be fully evaluated (e.g., see definition of \((+)\) above) and no suspension control is necessary, i.e., it is ensured that the external function call does not suspend for all arguments. Otherwise, the raw interface (see below) must be used. For instance, the Prolog code implementing \( \text{prim}_{\text{Int}+} \) contained in the Prolog library \( \text{prim_standard.pl} \) is as follows (note that the arguments of \((+)\) are passed in reverse order to \( \text{prim}_{\text{Int}+} \) in order to ensure a left-to-right evaluation of the original arguments by the calls to \((\#)\)):

```
\text{prim}_{\text{Int}+}(Y,X,R) :- R is X+Y.
```

3. The **standard interface for I/O actions**, i.e., external functions with result type \( \text{IO a} \), assumes
that the I/O action is implemented as a predicate (with a possible side effect) that instantiates the last argument to the returned value of type “a”. For instance, the primitive predicate `prim_getChar` implementing prelude I/O action `getChar` can be implemented by the Prolog code

```
prim_getChar(C) :- get_code(N), char_int(C,N).
```

where `char_int` is a predicate relating the internal Curry representation of a character with its ASCII value.

4. If some arguments passed to the external functions are not fully evaluated or the external function might suspend, the implementation must follow the structure of the PAKCS runtime system by using the raw interface. In this case, the name of the external entry must be suffixed by “[raw]” in the `prim_c2p` file. For instance, if we want to use the raw interface for the external function `prim_Int_plus`, the specification file `Prelude.prim_c2p` must have an entry of the form

```
<primitive name="prim_Int_plus" arity="2">
  <library>prim_standard</library>
  <entry>prim_Int_plus[raw]</entry>
</primitive>
```

In the raw interface, the actual implementation of an `n`-ary external function consists of the definition of an `(n+3)`-ary predicate `pred`. The first `n` arguments are the corresponding actual arguments. The `(n+1)`-th argument is a free variable which must be instantiated to the result of the function call after successful execution. The last two arguments control the suspension behavior of the function (see [5] for more details): The code for the predicate `pred` should only be executed when the `(n+2)`-th argument is not free, i.e., this predicate has always the SICStus-Prolog block declaration

```
?- block pred(?,...,?,?-,?).
```

In addition, typical external functions should suspend until the actual arguments are instantiated. This can be ensured by a call to `ensureNotFree` or `($#)` before calling the external function. Finally, the last argument (which is a free variable at call time) must be unified with the `(n+2)`-th argument after the function call is successfully evaluated (and does not suspend). Additionally, the actual (evaluated) arguments must be dereferenced before they are accessed. Thus, an implementation of the external function for adding integers is as follows in the raw interface:

```
?- block prim_Int_plus(?,...,?,?-,?-).  
prim_Int_plus(RY,RX,Result,E0,E) :-  
  deref(RX,X), deref(RY,Y), Result is X+Y, E0=E.
```

Here, `deref` is a predefined predicate for dereferencing the actual argument into a constant (and `derefAll` for dereferencing complex structures).

The Prolog code implementing the external functions must be accessible to the run-time system of PAKCS by putting it into the directory containing the corresponding Curry module or into the
system directory \textit{pakcshome/curry2prolog/lib\_src}. Then it will be automatically loaded into the run-time environment of each compiled Curry program.

Note that arbitrary functions implemented in C or Java can be connected to PAKCS by using the corresponding interfaces of the underlying Prolog system.
Index

<, 127
***, 87
*, 61, 85
**#, 59
+, 61, 85
++, 59
--#, 28
--compact, 38
--fcypp, 38
-, 61, 85
-, 59
-fpopt, 38
., 63
../=, 63
./=, 54
./, 54
.==, 63
.&&, 62
.pakcsrc, 15
.<, 63
.<, 54
.<=, 63
.<=, 54
., 63
.>, 63
.>>, 55
.>=, 63
.>=, 54
./, 61, 85
//, 156
/#, 59
\, 53, 56
!:, 10
:&&, 163
:add, 9
:browse, 9
:cd, 10
:coosy, 11
:dir, 10
:edit, 10
:eval, 9
:fork, 11
:help, 8
:interface, 10
:load, 9
:modules, 10
:peval, 11
:programs, 10
:quit, 9
:reload, 9
:save, 11
:set, 10
:set path, 7
:show, 10
:source, 10
:type, 9
:usedimports, 10
:xml, 9, 11
==>, 53
=#, 59
@, 17
@author, 28
@cons, 28
@param, 28
@return, 28
@version, 28
#/=#, 59
#\#, 60
#==#, 59
#=>#, 60
#<=#, 60
#<==>#, 60
#<#, 60
#>#, 60
#\#, 60
&k&, 87
PAKCS, 8
{...}, 18
<*>., 127
<>., 132
<., 61
<., 82
addExtension, 82
addFormParam, 180
addHeadings, 183
addHours, 153
addListToFM, 159
addListToFM_C, 159
addMinutes, 153
addMonths, 153
addPageParam, 180
addRegionStyle, 102
address, 182
addSeconds, 153
addSound, 180
addToFM, 159
addToFM_C, 159
addTrailingPathSeparator, 84
addYears, 153
AExpr, 229
aFloat, 212
AFuncDecl, 229
aInt, 212
align, 132
all_different, 61
al1C, 65
al1CHR, 54, 56
allDBInfos, 113, 118
allDBKeySpecs, 113, 118
allDBKeys, 113, 117, 119
allDifferent, 61
allfails, 12
allVars, 241, 265
allVarsInFunc, 236, 260
allVarsInProg, 231, 255
allVarsInRule, 237, 261
alwaysRequired, 244
anchor, 182
andC, 65
andCHR, 54, 56
angles, 137
annExpr, 242
annPattern, 242
annRule, 242
answerEncText, 179
answerText, 179
database programming, 35
dquote, 138
dquotes, 137
dropDrive, 83
dropExtension, 82
dropExtensions, 83
dropFileName, 83
dropTrailingPathSeparator, 84
Dynamic, 77, 115
dynamic, 78
dynamicExists, 68
eBool, 213
eChar, 213
Edge, 162
edges, 167
eEmpty, 213
eFloat, 213
eInt, 213
element, 212
elemFM, 160
elemIndex, 120
elemIndices, 120
elemRBT, 170
elemsOf, 209
eIIsFM, 161
Emacs, 15
emap, 167
emphasize, 181
empty, 127, 130, 157, 164, 169, 212
emptyDefaultArray, 156
emptyErrorArray, 156
emptyFM, 159
emptySetRBT, 170
emptyTableRBT, 172
encapsulated search, 7
enclose, 136
encloseSep, 135
Encoding, 208
tity relationship diagrams, 35
EntryScroll, 103
eOpt, 213
eqFM, 160
equal, 166
equalFilePath, 84
equals, 139
ERD2Curry, 35
erd2curry, 35
eRep, 213
eRepSeq1, 214
eRepSeq2, 214
eRepSeq3, 215
eRepSeq4, 215
eRepSeq5, 216
eRepSeq6, 217
errorT, 69, 116
eSeq1, 214
eSeq2, 214
eSeq3, 215
eSeq4, 215
eSeq5, 216
eSeq6, 216
eString, 213
evalChildFamilies, 173
evalChildFamiliesIO, 174
evalCmd, 109
evalFamily, 173
evalFamilyIO, 174
evalSpace, 141
evalTime, 141
evaluate, 63
even, 105
Event, 96
exclusiveIO, 109
execCmd, 109
exists, 63
existsDBKey, 113, 117, 119
exitGUI, 101
exitWith, 151
exp, 86
expires, 180
Expr, 250
extended, 76
external function, 277
extSeparator, 82
factorial, 104
fail, 53, 56
failT, 69, 117
false, 62
family, 173
FCYPP, 38
fcypp, 38
field label, 18
FilePath, 81
fileSize, 71
fileSuffix, 81
fillCat, 134
fillEncloseSep, 135
fillEncloseSepSpaced, 136
fillSep, 134
filterFM, 160
find, 120
findall, 7
findFileInLoadPath, 75
findFirst, 7
findIndex, 120
findIndices, 121
firewall, 47
first, 12, 87
fix, 87
Fixity, 249
FlatCurry, 47
flatCurry2Xml, 268
flatCurry2XmlFile, 268
flatCurryFileName, 253
flatCurryIntName, 253
FlexRigidResult, 268
float, 137, 211
floatType, 224
FM, 158
fmSortBy, 161
fmToList, 161
fmToListPreOrder, 161
focusInput, 102
fold, 173
foldChildren, 174
foldFM, 160
foldValues, 148
form, 179
formatMarkdownFileAsPDF, 192
formatMarkdownInputAsPDF, 192
formBodyAttr, 179
formCSS, 179
formEnc, 179
formMetaInfo, 179
FormParam, 176
free, 11
free variable mode, 9, 11
freeExpr, 239, 263
freeVars, 239, 263
fromJust, 124
fromMarkdownText, 192
fromMaybe, 124
FrontendParams, 73
FrontendTarget, 72
fullPath, 76
funcArgs, 236, 260
funcArity, 235, 259
funcBody, 236, 260
FuncDecl, 249
funcName, 225, 235, 259
funcRHS, 236, 260
funcRule, 236, 260
function
  external, 277
functional pattern, 16
funcType, 236, 260
funcVis, 225
funcVisibility, 235, 259
garbageCollect, 140
garbageCollectorOff, 140
garbageCollectorOn, 140
GDecomp, 163
glelem, 166
generateCompactFlatCurryFile, 244
germanLatexDoc, 187
getAbsolutePath, 72
getAllFailures, 49
getAllSolutions, 49
getAllValues, 49
getArgs, 150
getAssoc, 110
gGetClockTime, 152
gGetContents, 108
gGetContents0fUrl, 193
getCookies, 186
getCPUTime, 150
gGetCurrentDirectory, 71
gGetCursorPosition, 102
gGetDB, 68, 116
gGetDBInfo, 113, 118, 119
gGetDBInfos, 113, 118, 120
gGetDirectoryContents, 71
gGetDynamicSolution, 78
gGetDynamicSolutions, 78
gGetElapsedTime, 150
gGetEnviron, 150
gGetFileInPath, 81
gGetFlexRigid, 268
gGetHomeDirectory, 71
gGetHostname, 150
gGetKnowledge, 78
gGetLoadPath, 75
gGetLoadPathForFile, 75
gGetLoadPathForModule, 75
gGetLocalTime, 152
gGetModificationTime, 71
gGetOneSolution, 49
gGetOneValue, 49
gGetOpenFile, 103
gGetOpenFileWithTypes, 103
gGetOpt, 90
gGetOpt', 90
gGetPID, 150
gGetPortInfo, 65
gGetProcessInfos, 140
gGetProgName, 150
gGetRandomSeed, 168
gGetRcVar, 74
gGetRcVars, 74
gGetSaveFile, 104
gGetSaveFileWithTypes, 104
gGetSearchPath, 82
gGetSearchTree, 49
gGetTemporaryDirectory, 72
gGetUrlParameter, 186
gGetValue, 101
Global, 90
global, 91
GlobalSpec, 90
gmap, 167
Goal, 53, 56
Graph, 163
ground, 55
group, 122, 131
groupBy, 122
groupByIndex, 113, 120
GuiPort, 92
GVar, 91
gvar, 91
h1, 181
h2, 181
h3, 181
h4, 181
h5, 181
Handle, 106
hang, 131
hasDrive, 83
hasExtension, 82
hasTrailingPathSeparator, 84
hcat, 134
hClose, 107
headedTable, 183
hempty, 181
hEncloseSep, 135
hFlush, 107
hGetChar, 108
hGetContents, 108
hGetLine, 108
hiddenfield, 185
hIsEOF, 107
hIsReadable, 108
hIsTerminalDevice, 108
hIsWritable, 108
hPrint, 108
hPutChar, 108
hPutStr, 108
hPutStrLn, 108
hReady, 108
href, 182
hrule, 183
hSeek, 107
hsep, 133
htmldir, 77
HtmlExp, 175
HtmlForm, 176
HtmlHandler, 175
htmlIsoUmlauts, 185
HtmlPage, 178
htmlQuote, 185
htmlSpecialChars2tex, 187
htxt, 181
htxts, 181
hWaitForInput, 107
hWaitForInputOrMsg, 107
hWaitForInputs, 107
hWaitForInputsOrMsg, 107
i2f, 61, 85
identicalVar, 154
idOfCgiRef, 179
ilog, 104
image, 183
imageButton, 184
inCurrySubdir, 74
inCurrySubdirModule, 75
indeg, 166
indeg', 167
index, 113, 119
indomain, 61
init, 123
inits, 122
inline, 183
inn, 165
inn', 167
insEdge, 164
insEdges, 164
insertBy, 123
insertMultiRBT, 170
insertRBT, 170
insNode, 164
insNodes, 164
installDir, 73
int, 137, 211
interactive, 12
intercalate, 121
intersect, 121
intersectBy, 121
intersectFM, 160
intersectFM_C, 160
intersectRBT, 170
intersperse, 121
intForm, 187
intFormMain, 187
intToDigit, 52
intType, 224
invf1, 88
invf2, 88
invf3, 88
invf4, 88
invf5, 88
IOMode, 106
IORef, 109
ioType, 224
isAbsolute, 80, 85
isAlpha, 52
isAlphaNum, 52
isAscii, 51
isAsciiLower, 51
isAsciiUpper, 51
isBaseType, 225
isBigComment, 246
isBinDigit, 52
isCase, 240, 263
isCode, 246
isComb, 239, 263
isCombTypeConsCall, 238, 262
isCombTypeConsPartCall, 238, 262
isCombTypeFuncCall, 238, 262
isCombTypeFuncPartCall, 238, 262
isComment, 246
isConsCall, 241, 264
isConsPartCall, 241, 264
isConsPattern, 242, 266
isControl, 52
isDigit, 52
isDrive, 83
isEmpty, 130, 147, 157, 165, 169
isEmptyFM, 160
isEmptySetRBT, 170
isEmptyTable, 172
isEOF, 107
isExternal, 236, 260
isExtSeparator, 82
isFree, 239, 263
isFuncCall, 240, 264
isFuncPartCall, 241, 264
isFunctionalType, 225
isFuncType, 234, 258
isGround, 154, 241, 265
isHexDigit, 52
isInfixOf, 123
is1OReturnType, 225
is1OType, 225
isJust, 124
isKnown, 79
isLatin1, 51
isLeft, 80
isLet, 239, 263
isLetter, 246
isLit, 239, 263
isLower, 52
isMeta, 246
isModuleHead, 246
isNothing, 124
isOctDigit, 52
isOr, 239, 263
isPathSeparator, 81
isPolyType, 225
isPosix, 151
isPrefixOf, 122
isPrelude, 227
isqrt, 104
isRelative, 85
isRight, 80
isRuleExternal, 237, 261
isSearchPathSeparator, 82
isSmallComment, 246
isSpace, 52
isSuffixOf, 123
isTCons, 234, 258
isText, 246
isTVar, 234, 258
isTypeSyn, 232, 256
isUpper, 52
isValid, 84
isVar, 154, 239, 263
isWindows, 151
italic, 182
joinDrive, 83
joinModuleIdentifiers, 74
joinPath, 84
JSBranch, 112
jsConsTerm, 112
JSExp, 110
JSFDecl, 112
JSStat, 111
Key, 114
keyOrder, 161
KeyPred, 114
keysFM, 161
lab, 165
lab', 166
labEdges, 167
label, 18
labeling, 61
LabelingOption, 57
labNode', 166
labNodes, 167
labUEdges, 167
labUNodes, 167
langle, 138
last, 123
lbrace, 138
lbracket, 138
LEdge, 162
lefts, 80
leqChar, 171
leqCharIgnoreCase, 171
leqLexGerman, 171
leqList, 171
leqString, 171
leqStringIgnoreCase, 171
let, 16
letBinds, 239, 262
letBody, 239, 263
line, 130
linebreak, 131
linesep, 130
list, 136
list2ac, 227
list2CategorizedHtml, 174
ListBoxScroll, 103
listenOn, 126, 149
listenOnFresh, 149
listPattern, 227
listSpaced, 136
listToDefaultArray, 157
listToDeq, 158
listToErrorArray, 157
listToFM, 159
listToMaybe, 125
listType, 224
litem, 182
Literal, 253
literal, 238, 262
LNode, 162
log, 86
logBase, 86
logfile, 77
lookup, 169
lookupFileInLoadPath, 75
lookupFileInPath, 81
lookupFM, 160
lookupModuleSourceInLoadPath, 75
lookupRBT, 172
lookupWithDefaultFM, 160
lparen, 137
LPath, 163
lpre, 165
lpre', 166
lsuc, 165
lsuc', 166
MailOption, 190
main, 65
mainWUI, 199, 207
makeRelative, 84
makeValid, 85
mapAccumL, 124
mapAccumR, 124
mapChildFamilies, 173
mapChildFamiliesIO, 174
mapChildren, 173
mapChildrenIO, 174
mapFamily, 173
mapFamilyIO, 174
mapFM, 160
mapMaybe, 125
mapMMaybe, 125
mapT, 69, 117
mapT_, 69, 117
mapValues, 148
markdown, 28
MarkdownDoc, 190
MarkdownElem, 190
markdownEscapeChars, 192
markdownText2CompleteHTML, 192
markdownText2CompleteLaTeX, 192
markdownText2HTML, 192
markdownText2LaTeX, 192
markdownText2LaTeXWithFormat, 192
match, 165
matchAny, 164
matchHead, 158
matchLast, 158
matrix, 100
max3, 105
maxFM, 161
maximize, 62
maximum, 123
maximumBy, 123
maximumFor, 62
maxlist, 105
maxValue, 148
maybeToList, 125
maybeType, 224
MContext, 162
MenuItem, 97
mergeSort, 171
min3, 105
minFM, 161
minimize, 62
minimum, 123
minimumBy, 123
minimumFor, 62
minlist, 105
minusFM, 160
minValue, 148
missingArgs, 238, 262
missingCombArgs, 238, 262
mkGraph, 164
mkUGraph, 164
MName, 217
modifyIORef, 110
modNameToPath, 74
modsOfType, 226
mplus, 125
multipleSelection, 185

nbsp, 181
neg, 60, 62
neighbors, 165
neighbors’, 166
nest, 131
newDBEntry, 114, 119, 120
newDBKeyEntry, 114, 119
newIORef, 110
newNamedObject, 130
newNodes, 167
newObject, 129
newTreeLike, 169
nextBoolean, 168
nextInt, 168
nextIntRange, 168
nmap, 167
noChildren, 173
Node, 162
node’, 166
nodeRange, 165
nodes, 167
noGuard, 226
noHandlerPage, 189
noindex, 30
noNodes, 165
nonvar, 55
normalise, 84
notEmpty, 147

nub, 121
nubBy, 121

odd, 105
olist, 182
on, 87
onlyindex, 30
OpDecl, 248
openFile, 106
openNamedPort, 46, 47, 129
openPort, 46, 129
openProcessPort, 129
opFixity, 235, 259
opName, 235, 259
opPrecedence, 235, 259
opt, 212
OptDescr, 89
Option, 243
orC, 65
orExps, 239, 263
out, 165
out’, 166
outdeg, 166
outdeg’, 167
overlapWarn, 76

page, 180
pageBodyAttr, 180
pageCSS, 180
pageEnc, 180
pageLinkInfo, 180
pageMetaInfo, 180
PageParam, 178
pakcs, 8
PAKCS_LOCALHOST, 47
PAKCS_OPTION_FCPP, 38
PAKCS_SOCKET, 47
PAKCS_TRACEPORTS, 47
pakcsret, 15
par, 181
parens, 137
parensIf, 137
parseHtmlString, 189
Parser, 127
rcFileName, 73
rcParams, 76
readAbstractCurryFile, 223
readAnyQExpression, 156
readAnyQTerm, 155
readAnyUnqualifiedTerm, 155
readCgiServerMsg, 189
readCompleteFile, 109
readCSV, 66
readCSVFile, 66
readCSVFileWithDelims, 66
readCurry, 48, 223
readCurryWithParseOptions, 223
readFileWithXmlDocs, 210
readFirstFileInLoadPath, 75
readFlatCurry, 48, 253
readFlatCurryFile, 253
readFlatCurryInt, 254
readFlatCurryIntWithImports, 266
readFlatCurryIntWithImportsInPath, 266
readFlatCurryWithImports, 266
readFlatCurryWithImportsInPath, 266
readFlatCurryWithParseOptions, 253
readFM, 161
readGlobal, 91
readGVar, 91
readHex, 143, 144
readHtmlFile, 189
readInt, 143
readI0Ref, 110
readNat, 143, 144
readOct, 144
readPropertyFile, 143
readQTerm, 145
readQTermFile, 145
readQTermListFile, 145
readsAnyQExpression, 155
readsAnyQTerm, 155
readsAnyUnqualifiedTerm, 155
readScan, 246
readsQTerm, 145
readsTerm, 145
readsUnqualifiedTerm, 144
readTerm, 145
readUnqualifiedTerm, 145
readUnsafeXmlFile, 210
readUntypedCurry, 223
readUntypedCurryWithParseOptions, 223
readXmlFile, 210
recip, 86
ReconfigureItem, 95
record syntax, 18
RedBlackTree, 168
redirect, 180
registerCgiServer, 189
registerPort, 65
removeDirectory, 71
removeEscapes, 192
removeFile, 72
removeRegionStyle, 102
renameDirectory, 71
renameFile, 72
Rendering, 193, 200
renderList, 199, 207
renderTaggedTuple, 199, 207
renderTuple, 199, 207
rep, 212
replace, 122
replaceBaseName, 83
replaceChildren, 173
replaceChildrenIO, 174
replaceDirectory, 84
replaceExtension, 82
replaceFileName, 83
repSeq1, 213
repSeq2, 214
repSeq3, 215
repSeq4, 215
repSeq5, 216
repSeq6, 216
RequiredSpec, 244
requires, 244
resetbutton, 184
resultType, 226, 234, 258
retract, 78
returnT, 69, 116
rights, 80
rnmAllVars, 241, 265
rnmAllVarsInFunc, 237, 260
rnmAllVarsInProg, 231, 255
rnmAllVarsInRule, 238, 261
rnmAllVarsInTypeExpr, 234, 258
rnmProg, 231, 255
rotate, 158
round, 85
row, 100
rparen, 137
Rule, 249
ruleArgs, 237, 261
ruleBody, 237, 261
ruleExtDecl, 237, 261
runCgiServerCmd, 189
runCHR, 55
runCHRwithTrace, 55
runConfigControlledGUI, 100
runControlledGUI, 100
runFormServerWithKey, 186
runFormServerWithKeyAndFormParams, 186
runGUI, 100
runGUIwithParams, 100
runHandlesControlledGUI, 101
runInitControlledGUI, 101
runInitGUI, 100
runInitGUIwithParams, 100
runInitHandlesControlledGUI, 101
runJustT, 70, 116
runNamedServer, 130
runPassiveGUI, 100
runQ, 68, 116
runT, 69, 116
runTNA, 70
safe, 14
satisfied, 63
satisfy, 127
scalarProduct, 60
scan, 246
scanl, 123
scanl1, 123
scanr, 124
scanr1, 124
sClose, 126, 150
searchPathSeparator, 82
SearchTree, 49
second, 87
SeekMode, 106
seeText, 102
select, 148
selection, 185
selectionInitial, 185
selector function, 19
selectValue, 148
semi, 138
semiBraces, 136
semiBracesSpaced, 136
send, 46, 129
sendMail, 190
sendMailWithOptions, 190
sep, 134
separatorChar, 80
seq1, 213
seq2, 214
seq3, 214
seq4, 215
seq5, 216
seq6, 216
seqStrActions, 51
sequenceMaybe, 125
sequenceT, 69, 117
sequenceT_, 69, 117
set functions, 7
set0, 146
set1, 146
set2, 147
set3, 147
set4, 147
set5, 147
set6, 147
set7, 147
setAssoc, 109
setConfig, 101
setCurrentDirectory, 71
setEnviron, 150
setExtended, 76
setFullPath, 76
space, 138
spawnConstraint, 154
specials, 77
spiceup, 36
Spicey, 36
split, 122
splitBaseName, 81
splitDirectories, 84
splitDirectoryBaseName, 81
splitDrive, 83
splitExtension, 82
splitExtensions, 82
splitFileName, 83
splitFM, 159
splitModuleName, 74
splitModuleIdentifiers, 74
splitOn, 122
splitPath, 81, 84
splitSearchPath, 82
splitSet, 64
spy, 14
sqrt, 86
squote, 138
quotes, 136
standardForm, 179
standardPage, 180
star, 127
stderr, 106
stdin, 106
stdout, 106
string, 137, 211
string2ac, 227
string2urlencoded, 186
stringList2ItemList, 174
stringPattern, 227
stringType, 224
stripCurrySuffix, 74
stripSuffix, 81
strong, 181
Style, 98
style, 183
styleSheet, 183
submitForm, 189
subset, 64
suc, 165
suc', 166
suffixSeparatorChar, 80
sum, 60, 123
system, 151
table, 183
TableRBT, 172
tableRBT2list, 172
tabulator stops, 6
tagOf, 209
tails, 122
takeBaseName, 83
takeDirectory, 84
takeDrive, 83
takeExtension, 82
takeExtensions, 83
takeFileName, 83
tan, 86
tanh, 87
tConsArgs, 234, 258
tConsName, 234, 258
teletype, 182
terminal, 127
TError, 67, 115
T>ErrorKind, 67, 115
testing programs, 33
testScan, 246
text, 130
textarea, 184
TextEditScroll, 103
textfield, 184
textOf, 209
textOfXml, 209
textstyle, 183
time, 13
timeoutOnStream, 129
toCalendarTime, 152
toClockTime, 152
toDayString, 153
toGoal1, 54
toGoal2, 54
toGoal3, 54
toGoal4, 54
XmlReads, 210
xmlReads, 211
xmlShow, 211
XmlShows, 210
xmlShows, 211
XOptConv, 211
XPrimConv, 210
XRepConv, 211
xtxt, 209