The Dalton Library

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1 Module Dalton_aux: Auxiliary definitions

This module define several auxiliary datatypes that are useful for the description of the ground
algebra. They are also used internally by the solver.

type 'a printer = Format.formatter -> 'a -> unit

Pretty-printing in the library is performed by the Format module. Therefore a printer of
values of type 'a may be viewed as a function of type 'a printer.

type printing = Format.formatter -> unit

Similarly, the printing of some message on a formatter may be abstractly represented by a
function of type printing.

type color = int
For drawing purposes, a color is represented by a simple integer, as in the Graphics module of the Objective Caml standard library.

1.1 Kinds

```ocaml
type kind =
  | Katom
  | Ktype
  | Krow

In the term algebra considered by the solver, terms may have one of the following kinds:
  • Katom for atoms,
  • Ktype for type,
  • Krow k for rows whose elements have kind k.
```

```ocaml
module Kind : sig end
[1.4]
```

1.2 Variances

```ocaml
type variance =
  | Covariant
  | Contravariant
  | Invariant

A variance is one of the three elements Covariant, Contravariant and Invariant.
```

```ocaml
module Variance : sig end
[1.5]
```

1.3 Constructor arguments

```ocaml
type constructor_arg = {
  variance : variance ;
  kind : kind ;
  ldestr : bool ;
  rdestr : bool ;
}
```

Signatures of type constructors are specified by giving for each argument a record of type constructor_arg.
1.4 Module Dalton_aux.Kind : Basic operations on kinds are provided by the module Variance.

module Kind : sig

val atomic : Dalton_aux.kind -> bool
    atomic k tests whether the kind k is atomic, i.e. is Katom or Krow Katom or Krow (Krow Katom) etc.

val rows : Dalton_aux.kind -> int
    rows k counts the number of Row in the kind k. For instance rows Katom and rows Ktype return 0, while rows (Krow Katom) and rows (Krow (Krow Ktype)) return respectively 1 and 2.

val fprint : Format.formatter -> Dalton_aux.kind -> unit
    fprint ppf k prints the kind k on the formatter ppf.

end

1.5 Module Dalton_aux.Variance : Basic operations on variances are provided by the module Variance.

module Variance : sig

val leq : Dalton_aux.variance -> Dalton_aux.variance -> bool
    leq v1 v2 tests whether the variance v1 is less than or equal to the variance v2 in the usual order on variance (which is the smallest order such that Covariant and Contravariant are less than Invariant.

val combine :
    Dalton_aux.variance -> Dalton_aux.variance -> Dalton_aux.variance
    combine v1 v2 calculates the combination of two variances.

val to_string : Dalton_aux.variance -> string
    to_string v gives a string representation of the variance v.

val fprint : Format.formatter -> Dalton_aux.variance -> unit
    fprint ppf v prints the variance v on the formatter ppf, using one of the three symbols "+", "-" and "=".

val fprint_name : Format.formatter -> Dalton_aux.variance -> unit


fprint_name ppf v prints the variance v on the formatter ppf, using its literal name (i.e. "covariant", "contravariant" or "invariant").

end

2 Module Dalton_sig: Library module parameters.
The Dalton solver is parametrized by several modules, which allow defining the term algebra, pretty-print, drawing and errors report. This module gives the expected signatures of this modules.

2.1 The ground algebra
module type GROUND = sig end [2.5]

2.2 Pretty-print
module type PRINT = sig end [2.6]

2.3 Error report
module type ERROR_REPORT = sig end [2.7]

2.4 Drawing
module type DRAW = sig end [2.8]

2.5 Module type Dalton_sig.GROUND: The ground term algebra is specified by an implementation of the signature GROUND.
module type GROUND = sig
  It must defines datatypes for constant bounds, type constructors and row labels; and simultaneously operations on them. One may distinguish two categories of such operations: 1. Algebraic operations, which allows manipulating the mathematical properties of the provided objects, 2. Computational operations, which relate merely the internal representation of these objects and allow efficient algorithms (e.g. hashing, comparison, pretty-print...)


2.5.1 Constant bounds

The client must provide two sets of atomic constants, one for representing variables lower bounds and another one for upper bounds. These two sets must be equipped with a semi-lattice structure.

```mkozc
module Lb : sig end
[2.5.4]
module Ub : sig end
[2.5.5]
module Lub : sig end
[2.5.6]
```

2.5.2 Row labels

```mkozc
module Label : sig end
[2.5.7]
```

2.5.3 Type constructors

```mkozc
module Type : sig end
[2.5.8]
```

end

2.5.4 Module Dalton_sig.GROUND.Lb: The module Lb specifies the set of constant lower bounds.

```mkozc
module Lb : sig

type t

The type of constant lower bound.

val bottom : t

    bottom is a distinguished lower bound. It is the bottom element of the semi-lattice.

val is_bottom : t -> bool

    is_bottom lb must return true if and only if lb is bottom.

val union : t -> t -> t

    union lb1 lb2 gives the union (according to the semi-lattice structure) of the lower bounds lb1 and lb2.

val leq : t -> t -> bool
```

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leq env lb1 lb2 tells whether lb1 is less than or equal to lb2 in the semi-lattice of constant lower bounds, i.e.: for all alpha, lb2 < alpha implies lb1 < alpha.

val compare : t -> t -> int
  A comparison function on constant lower bounds has to be provided. It is just used for computation and has no semantical meaning.

val normalize : t -> t
  normalize lb internally normalizes the lower bound lb.

val fprint : Format.formatter -> t -> unit
  fprint ppf lb pretty-prints the constant lower bound lb on the formatter ppf. (This function is used for printing of constants in constraints.)

val fprint_in_term : int -> Format.formatter -> t -> unit
  fprint_in_term ppf lb is used to print the constant lower bound lb on the formatter ppf when it appears in a term, in place of a non-negative variable which has no predecessor.
  An usual implementation may be: let fprint_in_term _ ppf lb = Format.fprintf ppf "> %a"
  fprint lb

val draw : t -> string list
end

2.5.5 Module Dalton_sig.GROUND.Ub: The module Ub specifies the set of constant upper bounds.

module Ub : sig

type t
  The type of constant upper bound.

val top : t
  top is a distinguished upper bound. It is the top element of the semi-lattice.

val is_top : t -> bool
  is_top lb must return true if and only if lb is top.

val inter :
  t -> t -> t
  inter lb1 lb2 gives the intersection (according to the semi-lattice structure) of the lower bounds lb1 and lb2.
val geq : t -> t -> bool
  geq l1b l2b tells wether l1b is greater than or equal to l2b in the semi-lattice of constant upper bounds.

val compare : t -> t -> int
  A comparison function on constant upper bounds has to be provided. It is just used for computation and has no semantical meaning.

val normalize : t -> t
  normalize l1b internally normalizes the lower bound l1b.

val fprint : Format.formatter -> t -> unit
  fprint ppf ub pretty-prints the constant upper bound ub on the formatter ppf. (This function is used for printing of constants in constraints.)

val fprint_in_term : 
  int -> Format.formatter -> t -> unit
  fprint_in_term ppf ub is used to print the constant lower bound ub on the formatter ppf when it appears in a term, in place of a non-negative variable which has no predecessor. An usual implementation may be: let fprint_in_term _ ppf ub = Format.fprintf ppf "< %.a" fprint ub

val draw : t -> string list
end

2.5.6 Module Dalton_sig.GROUND.Lub : The module Lub provides functions relating lower and upper bounds.

module Lub : sig

val leq : Dalton_sig.GROUND.Lb.t -> Dalton_sig.GROUND.Ub.t -> bool
  leq l1b ub returns true if and only if l1b is less than or equal to ub, i.e. there exists some alpha such that l1b < alpha and alpha < ub.

val geq : Dalton_sig.GROUND.Lb.t -> Dalton_sig.GROUND.Ub.t -> bool
  geq l1b ub returns true if and only if l1b is greater than or equal to ub, i.e. for all alpha and beta, alpha < ub and l1b < beta implies alpha < beta

val fprint_in_term :
  int -> Format.formatter ->
  Dalton_sig.GROUND.Lb.t -> Dalton_sig.GROUND.Ub.t -> unit

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fprint_in_term ppf lb ub is used to print a pair of a lower bound and an upper bound in a term. 
An usual implementation may be let fprint_in_term _ ppf lb ub = Format.fprintf ppf "> %a 1< %a" Lb.fprint lb Ub.fprint ub

end

2.5.7 Module Dalton_sig.GROUND.Label : The set of row labels is defined by the module Label.
module Label : sig

  type t
    The type of row labels.

  val compare : t -> t -> int
    A function compare defining a total order on row labels must be provided. This order is used for governing label mutations.

  val hash : t -> int
    hash lb1 returns a hash integer of the label lb1. If compare lb11 lb12 returns 0 then hash lb11 and hash lb12 must return the same integer.

  val fprint : Format.formatter -> t -> unit
    fprint ppf lb1 pretty-prints the row label lb1 on the formatter ppf.

end

2.5.8 Module Dalton_sig.GROUND.Type : Type constructors are given by the module Type.
module Type : sig

  type 'a t
    A type constructor (with its arguments) is represented by a value of type 'a t, where 'a is the type of the arguments.

  val ldestr_inv : bool
    The boolean constant ldestr_inv tells wether there exists a type constructor for which the left destructor propagates on an invariant argument.

  val rdestr_inv : bool
    The boolean constant rdestr_inv tells wether there exists a type constructor for which the right destructor propagates on an invariant argument.

  val ldestr : 'a t -> bool
idestr \ t \ returns \ false \ if \ the \ type \ \ t \ cannot \ be \ an \ argument \ of \ the \ left \ destructor.

val rdestr : 'a t -> bool
  rdestr \ t \ returns \ false \ if \ the \ type \ \ t \ cannot \ be \ an \ argument \ of \ the \ right \ destructor.

val compatible :
  'a t -> 'a t -> bool
  compatible \ t1 \ t2 \ indicates \ whether \ the \ type \ constructors \ \ t1 \ and \ \ t2 \ are \ compatible.

val map :
  (Dalton_aux.constructor_arg -> 'a -> 'b) ->
  'a t -> 'b t
  map \ f \ t \ returns \ the \ constructor \ \ t' \ obtained \ by \ replacing \ every \ son \ \ x \ of \ \ t \ by \ \ f \ i \ x \ (where \ \ i \ is \ the \ information \ of \ variance, \ kind \ and \ destructor \ propagation \ associated \ to \ the \ argument \ \ x \ in \ \ t).

val iter :
  (Dalton_aux.constructor_arg -> 'a -> unit) ->
  'a t -> unit
  iter \ f \ t \ applies \ \ f \ on \ every \ son \ \ x \ of \ \ t.

val iter2 :
  (Dalton_aux.constructor_arg -> 'a -> 'b -> unit) ->
  'a t -> 'b t -> unit
  Given \ two \ compatible \ constructors \ \ t1 \ and \ \ t2, \ \ iter2 \ f \ t1 \ t2 \ applies \ \ f \ on \ every \ pair \ of \ corresponding \ sons \ of \ \ t1 \ and \ \ t2. \ The \ result \ is \ not \ specified \ if \ \ t1 \ and \ \ t2 \ do \ not \ correspond.

val map2 :
  (Dalton_aux.constructor_arg -> 'a -> 'b -> 'c) ->
  'a t ->
  'b t -> 'c t
  Given \ two \ compatible \ constructors \ \ t1 \ and \ \ t2, \ \ map2 \ f \ t1 \ t2... \ The \ result \ is \ not \ specified \ if \ \ t1 \ and \ \ t2 \ do \ not \ correspond.

val for_all2 :
  (Dalton_aux.constructor_arg -> 'a -> 'b -> bool) ->
  'a t -> 'b t -> bool
  Given \ two \ compatible \ constructors \ \ t1 \ and \ \ t2, \ \ for_all \ f \ t1 \ t2 \ tests \ whether \ for \ all \ pair \ of \ sons \ \ x1 \ and \ \ x2, \ \ f \ i \ x1 \ x2 \ is \ true.

val hash : int t -> int
hash t returns a hash integer of the type constructor t which carries hashes of its sons.

type position
Values of type position represents a context of pretty-print. Distinguishing different contexts allows fine parenthesizing of imbricated terms.

val parenthesize : 
position -> 'a t -> bool 
parenthesize pos t returns a boolean indication whether the type constructor t must be parenthesized in context pos.

val fprint :
Format.formatter -> ('a -> bool) -> 
(Dalton_aux.constructor_arg -> 
   position -> Format.formatter -> 'a -> unit) -> 
   'a t -> unit 
fprint ppf skip f t pretty-prints the type constructor t on the formatter ppf. This function may
• Apply skip on each of t’s sons. If skip x is true then the son x does not carry any relevant information and may be skipped.
• Apply f pos ppf x on each of t’s sons in order to pretty-print it.
end

2.6 Module type Dalton_sig.PRINT: Printing of constraints may be parametrized by an implementation of the signature PRINT.

module type PRINT = sig
All printing are performed using the module Format of the Objective Caml standard library. A general purpose instance implementation is provided by Dalton_templates.Print[3.4].

val ghost : string
The string to be printed in place of ghost variables (i.e. unconstrained anonymous variables), e.g. "_"

val left_destructor : 'a Dalton_aux.printer -> Format.formatter -> 'a -> unit
val right_destructor :
   'a Dalton_aux.printer -> Format.formatter -> 'a -> unit
val left_destructor_skel :
   'a Dalton_aux.printer -> Format.formatter -> 'a -> unit
val right_destructor_skel :
   'a Dalton_aux.printer -> Format.formatter -> 'a -> unit
val same_skel : 'a Dalton_aux.printer -> Format.formatter -> 'a list -> unit
same_skel printer ppf list prints a same-skeleton constraint involving elements of the list list. A printer printer is given as argument for printing each element of the list.

val equal : 'a Dalton_aux.printer -> Format.formatter -> 'a list -> unit
same_skel printer ppf list prints an equality involving elements of the list list. A printer printer is given as argument for printing each element of the list.

leq lhs_printer rhs_printer ppf lhs rhs prints the inequality lhs < rhs on the formatter ppf. Two printers lhs_printer and rhs_printer are provided for printing the left-hand and right-hand sides, respectively.
val leq :
  'a Dalton_aux.printer ->
  'b Dalton_aux.printer -> Format.formatter -> 'a -> 'b -> unit

val rhs : 'a Dalton_aux.printer -> Format.formatter -> 'a list -> unit
  rhs_printer ppf list prints the right-hand side of an inequality, consisting in the elements of list the list. A printer printer is given as argument for printing each element of the list.

val cset_begin : Format.formatter -> unit
  cset_begin ppf is called before printing a constraint set on the formatter ppf.

val cset_end : Format.formatter -> unit
  cset_end ppf is called at the end of the printing a constraint set on the formatter ppf.

val cset_item : 'a Dalton_aux.printer -> Format.formatter -> 'a -> unit
  Every constraint c of a constraint set is printed on the formatter ppf by a call of the form cset_item printer ppf c where printer is a suitable printer for the constraint.

end

2.7 Module type Dalton_sig.ERROR_REPORT : The implementation of the signature ERROR_REPORT given to the library allows customizing error messages printed when unification, resolution or comparison fail.

module type ERROR_REPORT = sig
  A general purpose instance implementation is provided by Dalton_templates.ErrorReport[3.6].
2.7.1 Unification errors

val unification :  
  Format.formatter ->  
  term1:Dalton_aux.printing ->  
  term2:Dalton_aux.printing ->  
  explanation:Dalton_aux.printing -> unit  
  unification ppf "term1 "term2 "explanation reports an unification failure of the terms  
  term1 and term2. explanation gives a short explanation of the reason of the failure,  
  generated itself by one of the functions cycle or incompatible.

val cycle :  
  Format.formatter ->  
  variable:Dalton_aux.printing -> term:Dalton_aux.printing -> unit  
  cycle ppf variable term prints the explanation of an unification failure due to the  
  occur-check.

val incompatible :  
  Format.formatter ->  
  term1:Dalton_aux.printing -> term2:Dalton_aux.printing -> unit  
  cycle ppf "term1 "term2 prints the explanation of an unification failure due to  
  incompatibles type constructors.

2.7.2 Constraints solving errors

val ldestr : Format.formatter -> term:Dalton_aux.printing -> unit  
  ldestr ppf "term tells that the left-Destructor has been applied on the type term term  
  which cannot be so.

val rdestr : Format.formatter -> term:Dalton_aux.printing -> unit  
  rdestr ppf "term tells that the right-Destructor has been applied on the type term term  
  which cannot be so.

val inequality :  
  Format.formatter ->  
  lb:Dalton_aux.printing -> ub:Dalton_aux.printing -> unit  
  inequality ppf "lb "ub tells that a constraint is not satisfiable because it implies the  
  incorrect inequality lb < ub between constant bounds.
2.7.3 Schemes comparison

val incompatible_schemes : Format.formatter ->
  scheme1: Dalton_aux.printing ->
  scheme2: Dalton_aux.printing ->
  explanation: Dalton_aux.printing -> unit

  incompatible_schemes ppf "scheme1 "scheme2 "explanation reports that schemes
  scheme1 and scheme2 are not comparable, because of an unification error. explanation
  gives a short explanation of the reason of the failure, generated itself by one of the functions
  cycle or incompatible above.

val missing_desc : Format.formatter ->
  scheme: Dalton_aux.printing ->
  variable: Dalton_aux.printing ->
  term: Dalton_aux.printing -> unit

  missing_desc ppf "scheme "variable "term reports a comparison failure due to a
  variable instantiation.

val missing_constraint : Format.formatter ->
  scheme: Dalton_aux.printing ->
  constrain: Dalton_aux.printing -> unit

  missing_desc ppf "scheme "variable "term reports a comparison failure due to a
  missing inequality.

val missing_bound : Format.formatter ->
  scheme: Dalton_aux.printing ->
  constrain: Dalton_aux.printing ->
  explanation: Dalton_aux.printing option -> unit

  missing_desc ppf "scheme "variable "term reports a comparison failure due to a
  missing constant bound.

2.7.4 Minimal instance

val minimal : Format.formatter ->
  scheme: Dalton_aux.printing ->
  variables: Dalton_aux.printing -> unit

  minimal ppf "scheme "variables prints a message telling that the type scheme scheme
  has no minimal instance. variables prints a list of the variables of the scheme which do not
  have a minimal solution.
2.8 Module type Dalton_sig.DRAW : Graphical representation of schemes is controlled by a module of signature DRAW giving an implementation of drawing primitives.

module type DRAW = sig

This allows performing drawing on a variety of devices using appropriate external libraries. An example implementation using the Graphics library of the Objective Caml system is given in Dalton_templates.DrawGraphics[3.5].

type window
val draw_lines : window ->
  color:Dalton_aux.color -> lw:int -> (int * int) list -> unit
val draw_rect : window ->
  color:Dalton_aux.color ->
  lw:int -> x:int -> y:int -> w:int -> h:int -> unit
val draw_ellipse : window ->
  color:Dalton_aux.color ->
  lw:int -> x:int -> y:int -> rx:int -> ry:int -> unit
val fill_rect : window ->
  color:Dalton_aux.color -> x:int -> y:int -> w:int -> h:int -> unit
val fill_ellipse : window ->
  color:Dalton_aux.color -> x:int -> y:int -> rx:int -> ry:int -> unit
val fill_poly : window ->
  color:Dalton_aux.color -> (int * int) list -> unit
val draw_text : window ->
  color:Dalton_aux.color ->
  ?name:string -> size:int -> x:int -> y:int -> string -> unit
val text_size :
  window -> ?name:string -> size:int -> string -> int * int
val draw_dotted_lines :
  window ->
  color:Dalton_aux.color -> (int * int) list -> unit
end

3 Module Dalton_templates : Templates of module parameters.

This unit provides templates of modules which may be used as argument for the solver's functor.
3.1 Pretty-print

module Print : Dalton_sig.PRINT
    [3.4]

3.2 Drawing

module DrawGraphics : sig end
    [3.5]

3.3 Error report

module ErrorReport : Dalton_sig.ERROR_REPORT
    [3.6]

3.4 Module Dalton_templates.Print: The module Print provides a standard style for pretty-printing constraints.

module Print : sig

val ghost : string
val left_destructor :
  (Format.formatter -> 'a -> unit) -> Format.formatter -> 'a -> unit
val right_destructor :
  (Format.formatter -> 'a -> unit) -> Format.formatter -> 'a -> unit
val left_destructor_skel :
  (Format.formatter -> 'a -> unit) -> Format.formatter -> 'a -> unit
val right_destructor_skel :
  (Format.formatter -> 'a -> unit) -> Format.formatter -> 'a -> unit
val print_list :
  (Format.formatter -> 'a -> unit) ->
  string -> Format.formatter -> 'a list -> unit
val same_skel :
  (Format.formatter -> 'a -> unit) -> Format.formatter -> 'a list -> unit
val equal :
  (Format.formatter -> 'a -> unit) -> Format.formatter -> 'a list -> unit
val leq :
  (Format.formatter -> 'a -> unit) ->
  (Format.formatter -> 'b -> unit) -> Format.formatter -> 'a -> 'b -> unit
val lhs :
  (Format.formatter -> 'a -> unit) -> Format.formatter -> 'a list -> unit
val rhs :
  (Format.formatter -> 'a -> unit) -> Format.formatter -> 'a list -> unit
val first : bool Pervasives.ref
val cset_begin : 'a -> unit
val cset_item :
  (Format.formatter -> 'a -> unit) -> Format.formatter -> 'a -> unit
val cset_end : Format.formatter -> unit
end

3.5 Module Dalton_templates.DrawGraphics: The module DrawGraphics provides graphics primitives for the graphics library from the Objective Caml distribution.

module DrawGraphics : sig

  type window = unit

  val draw_lines :
    unit -> color:Graphics.color -> lw:int -> (int * int) list -> unit

  val draw_curves :
    unit ->
    color:Graphics.color -> lw:int ->
    int * int -> ((int * int) * (int * int) * (int * int)) list -> unit

  val draw_rect :
    unit ->

  val draw_ellipse :
    unit ->
    color:Graphics.color ->
    lw:int -> x:int -> y:int -> rx:int -> ry:int -> unit

  val fill_rect :
    unit -> color:Graphics.color -> x:int -> y:int -> w:int -> h:int -> unit

  val fill_ellipse :
    unit -> color:Graphics.color -> x:int -> y:int -> rx:int -> ry:int -> unit

  val fill_poly : unit -> color:Graphics.color -> (int * int) list -> unit

  val draw_text :
    unit ->
    color:Graphics.color ->
    ?name:string -> size:int -> x:int -> y:int -> string -> unit

  val text_size : unit -> ?name:string -> size:int -> string -> int * int

  val dotted_lines :
    ?'a -> color:Graphics.color -> (int * int) list -> unit
end


module ErrorReport : sig


val unification :
  Format.formatter ->
  term1:(Format.formatter -> unit) ->
  term2:(Format.formatter -> unit) ->
  explanation:(Format.formatter -> unit) -> unit
val cycle :
  Format.formatter ->
  variable:(Format.formatter -> unit) ->
  term:(Format.formatter -> unit) -> unit
val incompatible :
  Format.formatter ->
  term1:(Format.formatter -> unit) ->
  term2:(Format.formatter -> unit) -> unit
val minimal :
  Format.formatter ->
  scheme:(Format.formatter -> unit) ->
  variables:(Format.formatter -> unit) -> unit
val ldestr : Format.formatter -> term:(Format.formatter -> unit) -> unit
val rdestr : Format.formatter -> term:(Format.formatter -> unit) -> unit
val inequality :
  Format.formatter ->
  lb:(Format.formatter -> unit) -> ub:(Format.formatter -> unit) -> unit
val incompatible_schemes :
  Format.formatter ->
  scheme1:(Format.formatter -> unit) ->
  scheme2:(Format.formatter -> unit) ->
  explanation:(Format.formatter -> unit) -> unit
val missing_desc :
  Format.formatter ->
  scheme:(Format.formatter -> unit) ->
  variable:(Format.formatter -> unit) ->
  term:(Format.formatter -> unit) -> unit
val missing_constraint :
  Format.formatter ->
  scheme:(Format.formatter -> unit) ->
  constrain:(Format.formatter -> unit) -> unit
val missing_bound :
  Format.formatter ->
  scheme:(Format.formatter -> unit) ->
  constrain:(Format.formatter -> unit) ->
  explanation:(Format.formatter -> unit) option -> unit
end
4 Module Dalton: The core of the library

module Make : functor (Ground : Dalton_sig.GROUND) ->
  functor (Print : Dalton_sig.PRINT) ->
    functor (Draw : Dalton_sig.DRAW) ->
      functor (Report : Dalton_sig.ERROR_REPORT) -> sig end

4.1 Module Dalton.Make: The constraint solver comes as a functor parametrized
by four modules whose respective expected signatures are given in Dalton_sig[2].

module Make : sig
    Parameters:
    • Ground : Dalton_sig.GROUND
    • Print : Dalton_sig.PRINT
    • Draw : Dalton_sig.DRAW
    • Report : Dalton_sig.ERROR_REPORT

4.1.1 Constraint sets

type cset
    Constraint sets are represented by values of type cset.

val cset : unit -> cset
    Each invocation of cset () returns a new fresh empty constraint set.

val merge_cset : cset -> cset -> unit
    merge_cset cs1 cs2 merges the two constraint sets cs1 and cs2. After invoking this
    function, cs1 and cs2 point to the same constraint set cs which corresponds to the
    conjunction of the previous cs1 and cs2.

4.1.2 Terms

type node
    (Multi-equations of) Terms are represented by values of type node.

val variable : cset -> Dalton_aux.kind -> node
    variable cs k returns a fresh variable term of kind k. This variable may be used in the
    constraint set cs.
val variable_in_sk : node -> node

    variable_in_sk nd returns a fresh variable belonging to the same skeleton (and the same
constraint set) as the node nd.

val typ :
    cset -> node Ground.Type.t -> node

    typ cs t returns a fresh type term described by the type constructor t in the constraint set
cs. Every son of t must be a node belonging to cs.

val row :
    cset ->
    Ground.Label.t * node * node -> node

    row cs (lb1, nd_lb1, nd’) returns a fresh row node representing the term lb1:
nd_lb1, nd’ in the constraint set cs. nd_lb1 and nd’ must both belong to cs.

4.1.3 Setting constraints

type skeleton

    Multi-skeletons are represented by values of type skeleton.

type node_or_skeleton =
    | Nd of node
    | Sk of skeleton

    A value of type node_or_skeleton is either a node or a skeleton. Such values are used to
represent weak inequalities.

type unification_report

    Unification errors are described by a value of type unification_report. The
implementation of this type is not described. As a result, reports may be used only in order
to print error messages thanks to the function report_unification.

exception UnificationError of unification_report

    Above functions report unification errors by raising an exception UnificationError with an
appropriate report as argument.

val report_unification :
    Format.formatter -> unification_report -> unit

    report_unification ppf r pretty prints an error message on the formatter ppf describing
the unification error reported by r.

val same_skel : node -> node -> unit
same_skel nd1 nd2 sets a constraint nd1 ~ nd2. nd1 and nd2 must be nodes of the same constraint set and the same kind. If setting this constrain entails an unification error, an exception UnificationError is raised.

val equal : node -> node -> unit
    equal nd1 nd2 sets a constraint nd1 = nd2. nd1 and nd2 must be nodes of the same constraint set and the same kind. If setting this constrain entails an unification error, an exception UnificationError is raised.

val strong_leq : node -> node -> unit
    strong_leq nd1 nd2 sets the strong inequality ns1 < ns2. nd1 and nd2 must be nodes of the same constraint set and the same kind. If setting this constrain entails an unification error, an exception UnificationError is raised.

val weak_leq :
    node_or_skeleton -> node_or_skeleton -> unit
    weak_leq ns1 ns2 sets a weak inequality ns1 < ns2. ns1 and ns2 must be nodes or skeletons of the same constraint set.

val lower_bound : Ground.Lb.t -> node_or_skeleton -> unit
    lower_bound lb ns sets the weak inequality lb < ns.

val upper_bound : node_or_skeleton -> Ground.Ub.t -> unit
    upper_bound ns ub sets the weak inequality ns < ub.

4.1.4 Substitutions

type  subst = {
    lb : Ground.Lb.t -> Ground.Lb.t ;
       The substitution applied on lower bounds appearing in the constraint set.
    ub : Ground.Ub.t -> Ground.Ub.t ;
       The substitution applied on upper bounds appearing in the constraint set.
    typ : `a. `a Ground.Type.t -> `a Ground.Type.t ;
       The substitution applied on type constructors.
    label : Ground.Label.t -> Ground.Label.t ;
       The substitution applied on row labels.
}
A substitution may be applied while copying a scheme. It is defined by a record of four functions of type subst.

### 4.1.5 Schemes

```ml
module type SCHEME_ROOT = sig end
[4.1.6]
module Scheme : functor (Root : SCHEME_ROOT) -> sig end
[4.1.7]
end
```

#### 4.1.6 Module type Dalton.Make.SCHEME_ROOT : A (type) scheme is made of a constraint set and a series of entry nodes, its roots.

```ml
module type SCHEME_ROOT = sig

The same instance of the library may deal with several form of schemes. Each of them has to be described by an implementation of the signature SCHEME_ROOT.

type t

The type of schemes.

val cset : t -> Dalton.Make.cset

cset sh returns the constraint set of the scheme sh.

val copy :
    Dalton.Make.cset ->
    (Dalton.Make.node -> Dalton.Make.node) ->
    t -> t

    copy cset' f sh creates a new scheme sh' as follows:
    • the constraint set of sh' is cset',
    • each root of sh' is obtained by applying f on the corresponding root of sh.

val iter :
    (Dalton_aux.variance -> Dalton.Make.node -> unit) ->
    t -> unit

    iter f sh applies f on every root of sh (with the variance of the root as first argument).

val iter2 :
    (Dalton_aux.variance -> Dalton.Make.node -> Dalton.Make.node -> unit) ->
    t -> t -> unit

    iter2 f sh1 sh2 applies f on every pair of corresponding roots of sh1 and sh2 (with the variance of the roots as first argument).
```
val fprint : Format.formatter ->
   Dalton.Make.cset Dalton_aux.printer ->
   (Dalton_aux.variance -> Format.formatter -> Dalton.Make.node -> unit) ->
t -> unit
   fprint ppf print_cset print_node sh pretty prints the scheme sh on the formatter ppf.
   Two functions are provided as argument to allow printing of information handled by the solver:
   • print_cset ppf cset prints the constraint set cset on the formatter ppf
   • print_node v ppf nd prints the node nd of variance v on the formatter ppf.

end

4.1.7 Module Dalton.Make.Scheme : The functor scheme allows to build an implementation of functions dealing which each considered form schemes.

module Scheme : sig
  Parameters:
   • Root : Dalton.Make.SCHEME_ROOT

val copy : ?subst:Dalton.Make.subst -> Root.t -> Root.t
   copy ?subst sh returns a fresh copy of the type scheme sh. No particular assumption is made about the type scheme sh, but, for efficiency, it is more than a good idea to solve it previously.

val fprint : Format.formatter -> Root.t -> unit
   fprint ppf sh pretty-prints the scheme sh on the formatter ppf. The scheme sh is assumed to be solved.

val draw : Draw.window -> Root.t -> int -> int -> int * int
   draw window sh x y draws the scheme sh on the window window. The bottom left corner of the drawing has coordinates x and y and the function returns the coordinates of the upper right corner.

4.1.8 Resolution

type solve_report
   A solve report records an explanation of why the resolution of a scheme fails.

val report_solve :
   Format.formatter -> solve_report -> unit
report_solve ppf r pretty prints an error message on the formatter ppf corresponding to
the comparison report r.

val solve : Root.t -> solve_report option

solve sh solves the scheme sh. If this function returns None then the scheme sh has some
instances. Moreover, it is stored in a "solved" form which is preserved as long as no term or
constraint is added to its constraint set.

4.1.9 Comparison

type comparison_report

A comparison report records an explanation of the failure of the comparison of two schemes.

val report_comparison :
  Format.formatter -> comparison_report -> unit
  report_comparison ppf r pretty prints an error message on the formatter ppf describing
  the comparison report r.

val compare : Root.t -> Root.t -> comparison_report option

compare sh1 sh2 test whether sh2 is more general than sh1 (i.e. sh2 is a correct
implementation of sh1). It returns None if sh2 is effectively so. Otherwise, it returns Some r
when r is a report "explaining" why sh2 is not more general than sh1. The current
implementation assumes that sh1 and sh2 are solved.

val equivalent : Root.t -> Root.t -> bool

equivalent sh1 sh2 returns a boolean indicating whether the type schemes sh1 and sh2 are
equivalent. The current implementation assumes that sh1 and sh2 are in solved form.

4.1.10 Minimal instances

type minimal_report

A comparison report records an explanation of why a scheme has no minimal instance.

val report_minimal :
  Format.formatter -> minimal_report -> unit
  report_minimal ppf r pretty prints an error message on the formatter ppf describing the
  report r.

val has_minimal_instance : Root.t -> minimal_report option
hasminimal_instance sh tests whether the scheme sh has a minimal instance. If so, the function returns None. Otherwise, it returns Some r where r is a value of type minimal_report "explaining" why sh has no minimal instance. The current implementation assumes that sh is in solved form.