# Xpress-Kalis

## Reference Manual

**Release 9.1**

Last update 4 June, 2009

Published by Fair Isaac Corporation


## How to Contact the Xpress Team

**Information, Sales and Licensing**

*USA, CANADA AND ALL AMERICAS*

*Email:* XpressSalesUS@fico.com

*WORLDWIDE*

*Email:* XpressSalesUK@fico.com

*Tel:* +44 1926 315862
*Fax:* +44 1926 315854

FICO, Xpress team
Leam House, 64 Trinity Street
Leamington Spa
Warwickshire CV32 5YN
UK

**Product Support**

*Email:* Support@fico.com
(Please include *'Xpress'* in the subject line)

*Telephone:*

*NORTH AMERICA*
*Tel (toll free):* +1 (877) 4FI-SUPP
*Fax:* +1 (402) 496-2224

*EUROPE, MIDDLE EAST, AFRICA*
*Tel:* +44 (0) 870-420-3777
*UK (toll free):* 0800-0152-153
*South Africa (toll free):* 0800-996-153
*Fax:* +44 (0) 870-420-3778

*ASIA-PACIFIC, LATIN AMERICA, CARIBBEAN*
*Tel:* +1 (415) 446-6185
*Brazil (toll free):* 0800-891-6146

For the latest news and Xpress software and documentation updates, please visit the Xpress website at http://www.fico.com/xpress or subscribe to our mailing list.

## How to Contact Artelys

Artelys SA

*Information and Sales:* info-kalis@artelys.com
*Licensing and Product Support:* support-kalis@artelys.com

*Tel:* +33 1 44 77 89 00
*Fax:* +33 1 42 96 22 61

12, rue du Quatre Septembre
75002 Paris Cedex
France

For the latest news about Kalis, training course programs, and examples, please visit the Artelys website at http://www.artelys.com.

# Contents



# Chapter 1
# Introduction

## 1.1 Contents of this manual

This reference manual documents version 2009.1 of Xpress-Kalis.

This document and the software described in this document are furnished under a license or non-disclosure agreement, and may be used or copied only within the terms of such a license or non-disclosure agreement.

## 1.2 Constraint programming overview

Constraint programming  (CP) is a software technology becoming more widespread thanks to many successes whith effective solving of large, real-life, particularly combinatorial, problems. It provides a powerful technique for different problems such as scheduling, timetabling, resource allocation, or network configuration.

Research results from different fields (operations research, artificial intelligence, discrete mathematics, graph theory) are all involved in the core of Constraint Programming packages. Constraint Programming allows for representing many problems in a way which is very close to a natural language description, thanks to semantic constraints. Benefits are important: fast prototyping, compact code, easy modification, and good performance. It allows for specifying powerful decision support systems.

In order to have a quick overview of this technique, here are the basic elements required for a problem description:

A *constraint satisfaction problem* (CSP) is defined by:

- A set of decision variables $V = \{x_1, \ldots, x_n\}$
- For each variable, a set (or a range) of possible values called its *domain*
- A set of constraints on these variables.

The *arity* of a constraint corresponds to the number of variables that it involves. For discrete variables, domain values do not have to be consecutive (for example {1, 4, 6, 8}). For continuous variables, the domain is modelled as an interval.

An interesting notion is the *constraint graph*:

A CSP can be represented by a non-oriented graph where the edges symbolize the links between constraints and variables. The Figure 1.1 shows an example of a constraint graph for the following CSP:

Variables: $x, y, z$
Constraints: $x \neq y, y \neq z, z \neq x$

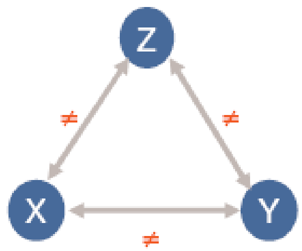



**Figure 1.1**: Constraint graph corresponding to the CSP

A *solution* to a CSP is an assignment of a value (belonging to its domain) to every variable, satisfying all the constraints.

In CP, constraints are used actively to deduce infeasible values and delete them from the domains of variables. This mechanism is called *constraint propagation*. It represents the core of Constraint Programming systems. Each constraint computes impossible values for its variables and informs other constraints. This process continues as long as new deductions are made.

Constraint propagation is associated with *tree search techniques* in order to find solutions or prove optimality. Each node and each decision will induce constraint propagation automatically. Many specific and efficient algorithms will be used in this propagation, but do not need to be known by the end-user. This allows persons who are familiar with problem modeling to quickly use such techniques for optimization or generation of solutions.

Solutions of a discrete CSP can be found by a systematic search on the set of possible assignments of values to variables. Other interval techniques are applied for continuous variables.

One may wish to find:

- just *one* feasible solution, without any choice preference
- *all* the solutions
- an *optimal* solution (or at least a nearly optimal solution) that optimizes a certain objective function defined on a subset of the variables of the problem

Solution search methods can be classified in two categories:

- Search methods that explore the space of the partial assignments
- Search methods that explore the space of complete assignments, generally in a stochastic way

The main reason for representing a problem as a CSP is that the formulation of the problem as a CSP is close to the original one in that: variables of the CSP directly correspond to the problem entities and the constraints can be expressed in a natural way without any translation to a set of linear inequalities as in the Mathematical Programming framework. This formulation is thus clearer, solutions are easier to represent, and search heuristics more direct.

## 1.3 What is Xpress-Kalis ?

Xpress-Kalis is a Constraint Programming modeler based upon the Artelys Kalis solver. The software is provided in the form of a Mosel module, *kalis*. Xpress-Mosel must be installed in order to be able to use Xpress-Kalis. Microsoft Windows users can work with Xpress-Kalis through the graphical environment Xpress-IVE. The module *kalis* extends the Mosel language with new ways of defining and solving Constraint Programming (CP) problems.

## 1.4 Prerequisites

This manual assumes some familiarity with the Mosel syntax. The reader is refered to the 'Mosel User Guide' for an introduction to working with Mosel. The 'Mosel Language Reference Manual' contains the complete documentation of the Mosel language. The 'Getting Started' manual explains how to work with Mosel models in the IVE environment.

# I. Paradigm

# Chapter 2
# Decision variables

Decision variables are represented in Xpress-Kalis by the types `cpvar` and `cpfloatvar`. They correspond respectively to finite domain variables taking their values in a given interval, or set of integers, called a domain and to continuous domain variables represented by real valued intervals. Conceptually the variables can be represented in the following way:

Decision variables are declared by using the standard Mosel syntax. For instance, the following code extract shows how to create a finite domain variable `my_cpvar`, a static array of cpvar `cpvar_array`, and a dynamic array of cpfloatvar `dyn_cpfloatvar_array`:

```
declarations
   my_cpvar             : cpvar
   cpvar_array          : array(1..10) of cpvar
   dyn_cpfloatvar_array : array(range) of cpfloatvar
end-declarations
```

Note that entries of dynamic arrays of domain variables (arrays declared as `dynamic` at their creation or arrays for which some or all of the index sets are not known at the declaration like `dyn_cpfloatvar_array` in the example above) must be created explicitly using the Mosel procedure `create`:

```
declarations
   dyn_cpfloatvar_array : array(range) of cpfloatvar
end-declarations
forall(i in 3..30) create (dyn_cpvar_array(i))
```

After its declaration, the second step in the creation of a domain variable consists of defining its domain with the procedure `setdomain`.

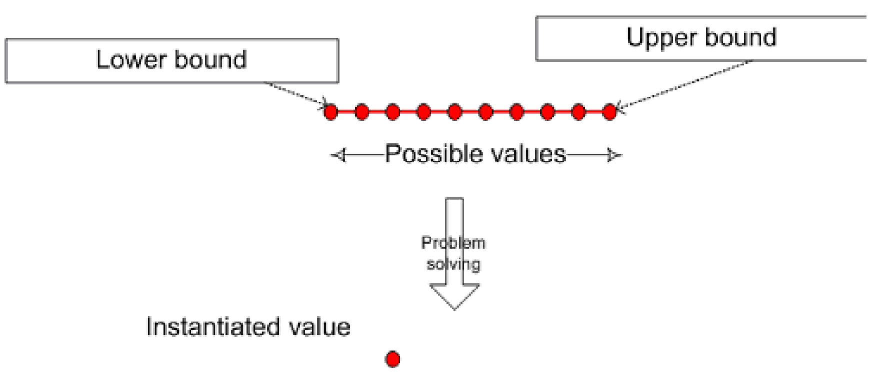



**Figure 2.1**: Conceptual representation of finite domain variables

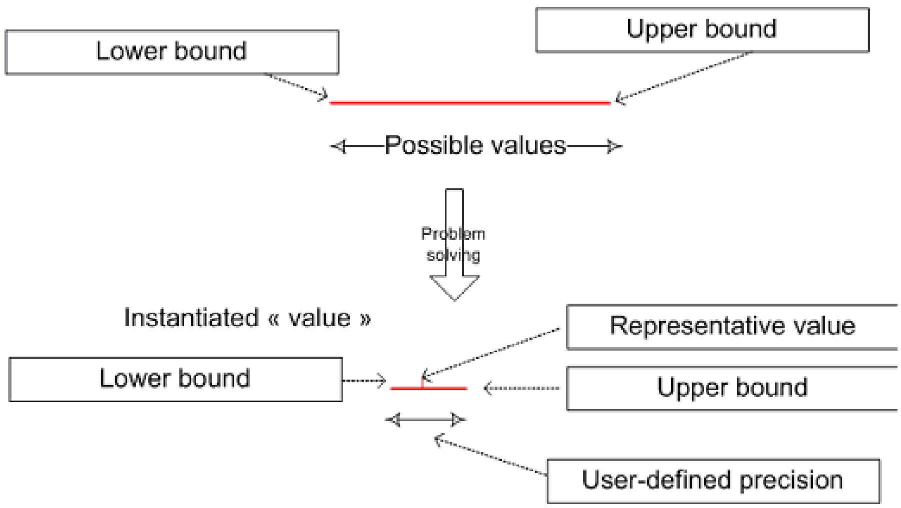



**Figure 2.2**: Conceptual representation of continuous variables

Domain variables are also used in the definition of constraints and search strategy.

Xpress-Kalis defines a set of functions for accessing and modifying `cpvar` and `cpfloatvar` states:

| | |
|---|---|
| `getlb` | Returns the current lower bound of a variable |
| `getub` | Returns the current upper bound of a variable |
| `getmiddle` | Returns the middle value of a variable |
| `getsize` | Returns the cardinality of the variable domain |
| `getval` | Returns the instantiation value of a variable |
| `is_fixed` | Tests if the variable passed in argument is instantiated |
| `getdegree` | Returns the degree of the variable |
| `gettarget` | Returns the target value of the variable passed in argument |
| `getrand` | Returns a random value belonging to the domain of a variable |
| `getnext` | Gets the next value in the domain of a finite domain variable |
| `getprev` | Gets the previous value in the domain of a finite domain variable |
| `contains` | Tests if a value is in the domain of a variable |
| `is_equal` | Tests if two variable domains are equal |
| `is_same` | Tests if two decision variables represent the same variable |
| `settarget` | Sets the target value of a variable |
| `setdomain` | Sets the domain of a variable |
| `setlb` | Sets the lower bound of a variable |
| `setub` | Sets the upper bound of a variable |
| `setval` | Instantiate the value of a variable |
| `instantiate` | Instantiate the value of a variable |
| `setprecision` | Sets the precision relativity and value of a continuous variable |
| `cp_show_var` | Shows the current domain of the variable |

# Chapter 3
# Constraints

Constraints represent logical restrictions on the values that decision variables can simultaneously take and that must be satisfied. There are various types of constraints that can be stated within Xpress-Kalis:

- Linear constraint (equation, inequality, disequality), *e.g.*: $x \neq y$, $x = y$, $x \leq y$ *etc.*
- Non-linear constraint (equation, inequality), *e.g.*: $x = y \, / \, z$, $x * y + 2 * ln(z) = exp(w)$, $x^2 + y^2 \leq z^2$ *etc.*
- Symbolic constraint, *e.g.*: *all-different*$(x, y, z)$ meaning $(x \neq y) \wedge (x \neq z) \wedge (x \neq z)$
- Logical relation, *e.g.*: $x \neq y \Rightarrow z = 3$
- User-defined constraints such as *generic_binary_constraint*$(x, y)$

All constraints are represented by the type `cpctr`.

| | |
|---|---|
| `cplinctr` | Linear constraints |
| `and` | Conjunction composite constraint |
| `or` | Disjunction composite constraint |
| `equiv` | Equivalence composite constraint |
| `implies` | Implication composite constraint |
| `cpnlinctr` | Non-linear constraints |
| `ln` | Natural logarithm of a non-linear expression |
| `exp` | Exponential of a non-linear expression |
| `distance` | Distance constraint |
| `abs` | Absolute value constraint |
| `all_different` | All different constraint |
| `cycle` | Cycle constraint |
| `maximum_minimum` | Maximum/minimum constraint |
| `occurrence` | Occurrence constraint |
| `element` | Element constraint |
| `generic_binary_constraint` | Generic Binary constraint |
| `distribute` | Distribute constraint with fixed bounds |
| `cumulative` | Cumulative constraint |
| `disjunctive` | Disjunctive constraint |
| `producer_consumer` | Producer Consumer constraint |

# Chapter 4

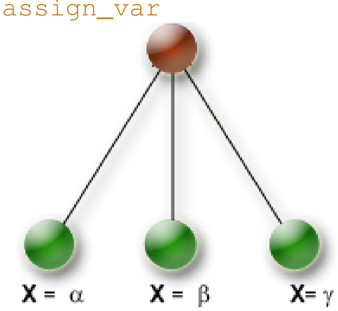
# Enumeration and search strategy

Since the combination of constraint solving and propagation mechanism is usually not sufficient to reduce all variable domains to a single value, an enumeration needs to be added to the problem definition to find feasible solutions or to prove that no such solution exists.

The search process is made by a branch and bound algorithm with depth-first exploration of the search tree. At each node, a propagation phase is triggered in order to detect possible inconsistencies and reduce the search space. If this phase detects an inconsistency, the algorithm backtracks and removes the effects of the previous decisions. If no inconsistency is detected, a branching process is applied recursively to the child nodes until a solution is found or until all the search space has been explored.

The way the branching is done is defined by branching schemes (type cpbranching). Six *branching schemes* are predefined in Xpress-Kalis:

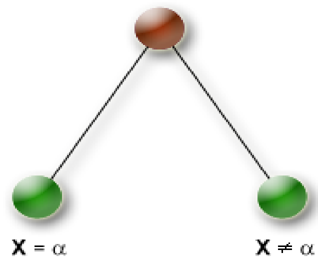
1. `assign_var`

   This branching scheme may be considered as the standard enumeration scheme in finite domain Constraint Programming. For a given branching variable it enumerates all values currently in its domain. A branch is formed by assigning a value to the branching variable, resulting in a variable number of branches per node (determined by the variable's domain size). Since this strategy tends to create a very wide search tree it is used preferably with small domains or if variable and value selection strategies are known that quickly lead to (good) feasible solutions.

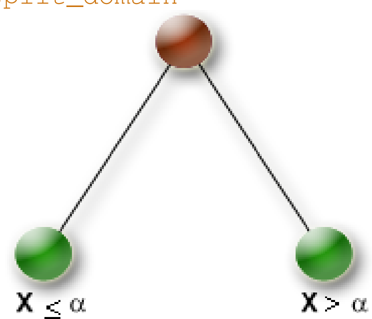
2. `assign_and_forbid`



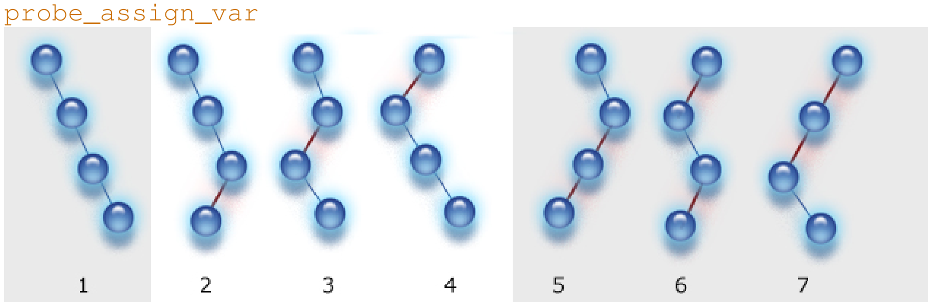

This branching scheme creates a binary search tree by creating two branches for a given branching variable. The first branch is formed by assigning a value to the branching variable, and the second branch, by forbidding this value for this variable.

3. `split_domain`



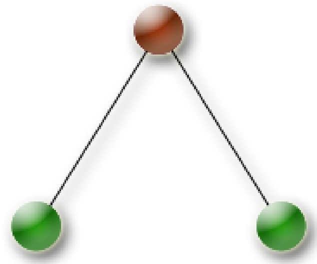

The split_domain strategy creates a binary search tree by splitting the domain of the branching variable into two intervals (all values less than or equal to the branching value in the first and all values greater than the branching value in the second). This strategy is the only possible choice for continuous variables and it is also applicable for finite domain variables. For the latter this strategy may be helpful if the initial domain sizes are relatively large. The strategy can be configured by choosing which branch to explore first and whether to stop applying it when domain sizes are reduced to less than a certain limit.

4. `probe_assign_var`



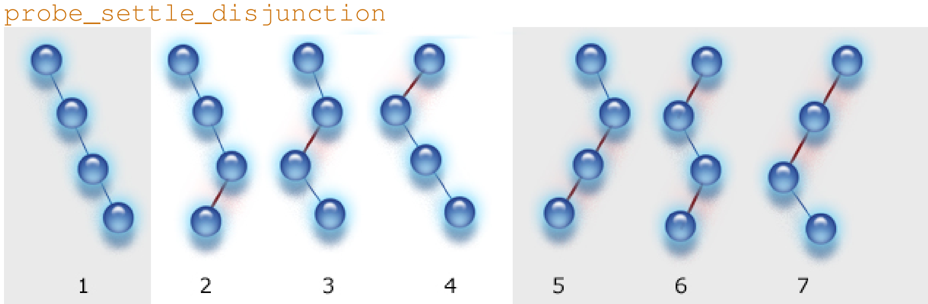

The probe_assign_var strategy is directly derived from the assign_var strategy which means that the branches created are the same. The difference lies in the completeness and the order in which branches are explored. Some of the possibles branches are skipped by limiting the global number of times that the heuristic (first branch created) may fail and the branching process is stopped when this counter exceeds a specified value. The picture below shows the order in which the branches are explored when the domains of all variables are reduced to two values. This strategy can be useful to apply local search to an already known solution (combined with the KALIS_NEAREST_VALUE value selection heuristic) or to explore the neighborhood of a heuristic solution to find quickly a first solution and avoid the thrashing behavior of the chronological backtracking algorithm used during the resolution process.

5. settle_disjunction




The settle_disjunction strategy creates a binary search tree by branching on the two possibilities defined by a disjunction. Recall that a disjunction can be written as `c1 or c2` where c1 and c2 are two constraints, the settle_disjunction strategy will create a branch for each constraint stating that it must hold. The strategy can be configured by choosing the first branch of the disjunction that will be explored during the search process.

6. probe_settle_disjunction




The probe_assign_var strategy is directly derived from the settle_disjunction strategy which means that the branches created by this strategy are the same. The difference lies in the completeness and the order in which branches are explored. Some of the possible branches are skipped by limiting the total number of times that the heuristic (first branch created) may fail and the branching process is stopped when this counter exceeds a specified value. The picture below shows the order in which the branches are explored when the domains of all variables are reduced to two values. This strategy can be useful to apply local search to a disjunctive scheduling problem for which a solution is already known (combined with the setfirstbranch and getactivebranch methods).

These predefined branching schemes are used in conjunction with variable (resp. disjunction) and value selection heuristics that fully define the way how the search tree will be explored.

Xpress-Kalis predefines several *variable selection heuristics*:

- KALIS_SMALLEST_DOMAIN
- KALIS_MAX_DEGREE
- KALIS_SDOMDEG_RATIO
- KALIS_SMALLEST_MAX
- KALIS_SMALLEST_MIN
- KALIS_LARGEST_MAX
- KALIS_LARGEST_MIN
- KALIS_MAXREGRET_UB

- KALIS_MAXREGRET_LB
- KALIS_INPUT_ORDER
- KALIS_WIDEST_DOMAIN (continuous variables)

... *value selection heuristics*:

- KALIS_MAX_TO_MIN
- KALIS_MIN_TO_MAX
- KALIS_MIDDLE_VALUE
- KALIS_RANDOM_VALUE

... and *disjunction selection heuristics*:

- KALIS_DISJ_INPUT_ORDER
- KALIS_DISJ_PRIORITY_ORDER

Xpress-Kalis offers several possibilities to define the search strategy:

- Use the predefined strategy provided by Xpress-Kalis.
- Build custom search strategies based on combinations of predefined branching schemes, variable and value selection heuristics.
- Define custom heuristics for variable and value selection.
- Add an optimization function (cost or objective function) for an enumeration and thus search for a feasible solution with the best (minimum or maximum) cost (optimal solution). We refer to this case as *optimization*, although, in practical applications one is typically only interested in good solutions that are found quickly, without necessarily spending time in proving that, indeed, the best solution is found.

The following example shows a specific problem and branching strategy with the corresponding search tree:

```
declarations
   x        : cpvar
   y        : cpvar
   strategy : array(1..2) of cpbranching
end-declarations
1 <= x ; x <= 3
1 <= y ; y <= 3
strategy(1) := split_domain(KALIS_SMALLEST_DOMAIN, KALIS_MIN_TO_MAX, {x})
strategy(2) := assign_var(KALIS_SMALLEST_DOMAIN, KALIS_MIN_TO_MAX, {y})
cp_set_branching(strategy)
```



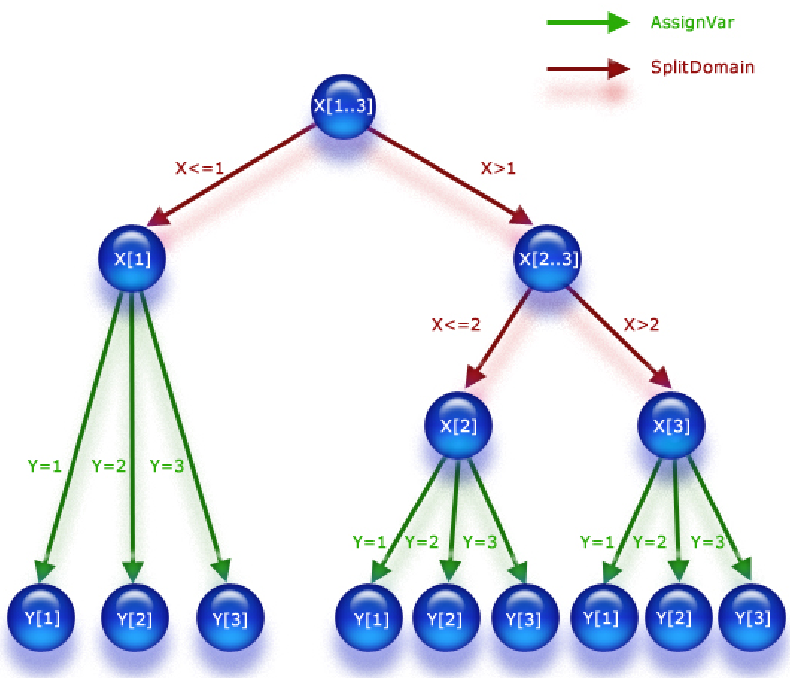



**Figure 4.1**: Example of search tree

# Chapter 5
# Scheduling

Scheduling plays an important role in manufacturing and engineering where it can have a major impact on the productivity of a process. The goal of scheduling is to optimize the production process by telling which operation to do, when, with which staff, and using which equipment.

Let's take the example of constructing a house. This task can be broken down into a set of smaller tasks:

- Grading and preparation of the site
- Foundations
- Framing
- Installation of windows and doors
- Roofing
- Siding
- Electricity
- Plumbing
- Underlayment
- Painting
- etc...

All these tasks must be carried out in a certain order: for example, laying the foundations cannot be done before the excavation and grading of the site. Moreover, certain tasks require specific resources (you need a plumber to do plumbing, a concrete mixer to do the carpentry *etc.*).

Tasks and resources are represented in Xpress-Kalis by special purpose types such as `cpresource` and `cptask`.

## 5.1 Tasks

A cptask is represented by three decision variables of type cpvar:

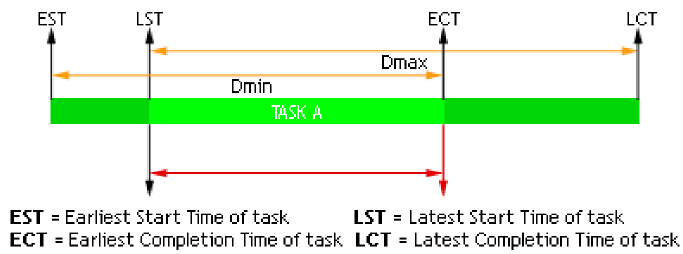
- *start* representing the starting time of the task
- *end* representing the ending time of the task

- *duration* representing the duration of the task

These three structural variables are linked by Xpress-Kalis with the following constraint: *start* + *duration* = *end*. The starting time variable represents two specific parameters of the task:

- the Earliest Start Time (EST, represented by the lower bound of the start variable) and its Latest Start Time (LST, represented by the upper bound of the start variable).
- The end variable represents two specific parameters of the task: the Earliest Completion Time (ECT, represented by the lower bound of the end variable) and its Latest Completion Time (LCT, represented by the upper bound of the end variable).
- The duration variable represents two specific parameters of the task: the minimum task duration (Dmin, represented by the lower bound of the duration variable) and the maximum task duration (Dmax, represented by the upper bound of the duration variable).

The picture below illustrates this:




Task attributes can be assigned or retrieved with the following methods:

- `getstart`
- `getend`
- `getduration`
- `setduration`
- `getname`
- `setname`
- `is_fixed`
- `addpredecessors`
- `setpredecessors`
- `addsuccessors`
- `setsuccessors`
- `setsetuptime`

## 5.2 Resources

A resource can be of two different types:

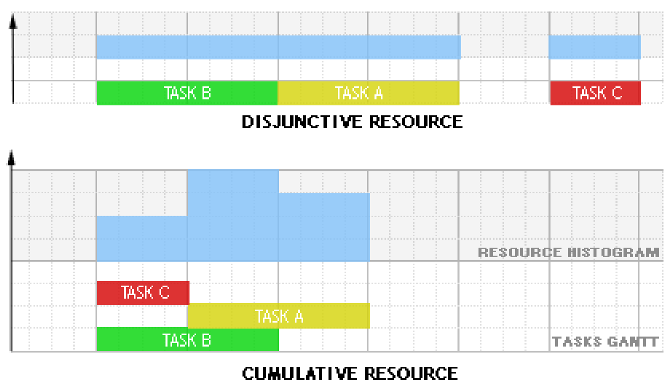
- *Disjunctive* when the resource can process only one task at a time (KALIS_UNARY_RESOURCE).
- *Cumulative* when the resource can process several tasks at the same time (KALIS_DISCRETE_RESOURCE).

Traditional examples of disjunctive resources are Jobshop scheduling problems. Cumulative resources are used for the Resource-Constrained Project Scheduling Problem (RCPSP)

Note that a disjunctive resource is semantically equivalent to a cumulative resource with maximal capacity one and unit resource usage for each task using this resource but this equivalence does not hold in terms of constraint propagation.

When defining a resource with Xpress-Kalis its initial capacity is specified. For a disjunctive resource the capacity value is always equal to one. The structural capacity of a resource does not vary over time but a maximal temporal capacity can be imposed at any point of time with the procedure `setcapacity`.

The following graphic shows an example with three tasks A, B and C executing on a disjunctive resource and on a cumulative resource with resource usage 3 for task A, 1 for task B, and 1 for task C.




Tasks require, provide, consume and produce resources:

- A task `requires` a resource if some amount of the resource capacity must be made available for the execution of the activity. The capacity is renewable, this means the required capacity becomes available again after the end of the task.
- A task `provides` a resource if some amount of the resource capacity is made available through the execution of the task. The capacity is renewable, that is, the provided capacity is available only during the execution of the task.
- A task `consumes` a resource if some amount of the resource capacity must be made available for the execution of the task and the capacity is non-renewable, that is, the consumed capacity is no longer available at the end of the task.
- A task `produces` a resource if some amount of the resource capacity is made available through the execution of the task and the capacity is non-renewable, that is, the produced capacity is definitively available after the start of the task.

Task productions, requirements, provisions and productions can be accessed with the following methods:

- consumes
- requires
- provides
- produces
- getconsumption
- getrequirement
- getprovision
- getproduction
- is_consuming
- is_requiring
- is_providing
- is_producing

Resources and tasks are declared by using the standard Mosel syntax. For instance, the following code extract shows how to create a task my_cptask, a static array of resources cpresource_array, and a dynamic array of cptask dyn_cptask_array:

```
declarations
   my_cptask        : cptask
   cpresource_array : array(1..10) of cpresource
   dyn_cptask_array : array(range) of cptask
end-declarations
```

Note that entries of dynamic arrays of tasks or resources (arrays declared as dynamic at their creation or arrays for which some or all of the index sets are not known at the declaration like dyn_cptask_array in the example above) must be created explicitly using the Mosel procedure create:

```
declarations
   dyn_cptask_array : array(range) of cptask
end-declarations
forall(i in 3..30) create (dyn_cptask_array(i))
```

After its declaration, the second step in the creation of a task or resource consists of defining somes attributes with the procedures set_task_attributes and set_resource_attributes.

## 5.3 Schedule

Tasks and resources form a *schedule*. The cp_schedule method allows to optimize a schedule with respect to any objective variable and implements advanced scheduling techniques specialized in makespan minimization. The creation of the schedule makespan can be automated by calling the getmakespan method that ensures automatically its computation.

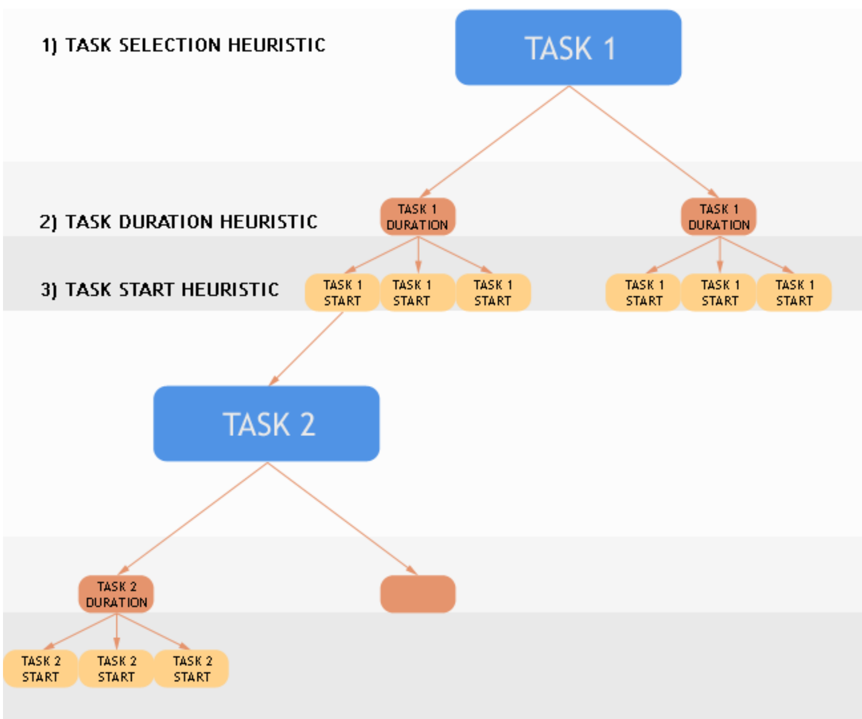
  

A custom scheduling optimization strategy can be specified by using the task_serialize branching scheme to select the task to be scheduled and value choice heuristics for its start and duration variables.

The task selection method can be any user Mosel method or it may be configured with the predefined strategies of Xpress-Kalis:

- KALIS_SMALLEST_ECT
- KALIS_SMALLEST_EST
- KALIS_SMALLEST_LCT
- KALIS_SMALLEST_LST
- KALIS_LARGEST_ECT
- KALIS_LARGEST_EST
- KALIS_LARGEST_LCT
- KALIS_LARGEST_LST

The picture below illustrates the definition of a task-based branching strategy:




Xpress-Kalis defines a set of functions for accessing and modifying cptask and cpresource states:

| | | |
|---|---|---|
| addpredecessors | Adds a set of predecessors for a task | p. 201 |
| addsuccessors | Adds a set of tasks as successors of a task | p. 203 |

| | | |
|---|---|---|
| consumes | Sets the minimal and maximal amount of resource consumed by a task for a particular resource | p. 223 |
| cp_get_default_schedule_strategy | Gets the default schedule search strategy of cp_schedule | p. 244 |
| cp_schedule | Optimizes the schedule with respect to an objective variable. | p. 221 |
| cp_set_schedule_strategy | Sets the schedule search strategy for cp_schedule | p. 243 |
| cp_show_schedule | Shows a textual representation of the current schedule | p. 205 |
| getassignment | Gets the cpvar representing the assignment of a task for a particular resource | p. 249 |
| getcapacity | Get the maximal capacity of a resource for a specific time period. | p. 238 |
| getconsumption | Gets the cpvar representing the consumption of a task for a particular resource | p. 209 |
| getduration | Gets the cpvar representing a task duration | p. 208 |
| getend | Gets the cpvar representing a task completion time | p. 207 |
| getmakespan | Gets the cpvar representing the makespan of the schedule. | p. 222 |
| getproduction | Gets the cpvar representing the production of a task for a particular resource | p. 213 |
| getprovision | Gets the cpvar representing the provision of a task for a particular resource | p. 215 |
| getrequirement | Gets the cpvar representing the requirement of a task for a particular resource | p. 211 |
| getsetuptime | Gets the sequence dependent setup times between two tasks | p. 241 |
| getstart | Gets the cpvar representing a task start time | p. 206 |
| has_assignment | Tests whether an assignment decision variable for a task and a particular resource exists | p. 252 |
| is_consuming | Tests whether a task consumes a specific resource | p. 217 |
| is_fixed | Tests if the variable passed in argument is instantiated | p. 118 |
| is_idletime | Tests if a timestep is an idle timestep for a resource | p. 256 |
| is_producing | Tests whether a task produces a specific resource | p. 219 |
| is_providing | Tests whether a task provides a specific resource | p. 220 |
| is_requiring | Tests whether a task requires a specific resource | p. 218 |
| produces | Sets the minimal and maximal amount of resource produced by a task for a particular resource | p. 229 |
| provides | Sets the minimal and maximal amount of resource provided by a task for a particular resource. | p. 232 |
| requires | Sets the minimal and maximal amount of resource required by a task for a particular resource | p. 226 |

# Chapter 6
# Linear relaxations

Some parts of an optimization problem may be best expressed and solved in the declarative (solver-independent) manner of Mathematical Programming (MP). Other parts benefit from constraint propagation and search directions provided by a CP solver. So why not trying to get the best of both worlds by combining the MP and CP approaches?

Xpress-Kalis allows you to benefit from CP and MIP hybridization in a clean and easy way by means of linear relaxations of the CP model. Xpress-Kalis can build automatically several linear (or mixed integer linear) relaxations of the CP problem and use Xpress-Optimizer to solve them.

This process can be fully configured ranging from a complete user definition of the relaxation and choice of when to launch the relaxation to a fully automatic relaxation.

Xpress-Kalis uses a double modeling approach by exchanging automatically and in bidirectional way, informations such as objective bounds, infeasibility, optimal relaxed solutions and reduced costs between the cp solver and the linear relaxations solver(s) during the search for a solution.

**Note:** the linear relaxation functionality of Xpress-Kalis can only be used if Xpress-Optimizer is installed and licensed.

## 6.1 Automatic relaxations

The following constraints can be relaxed automatically with Xpress-Kalis :

- Linear constraints
- all-different
- occurrence
- distribute
- Min/Max
- absolute value
- distance
- element
- cycle
- logical (implies, or ,and ,equiv)

To obtain an automatic relaxation of the whole problem, Xpress-Kalis takes the intersection of the relaxations of the constraints of the constraint programming model. Such a relaxation is obtained by a simple call to the function `cp_get_linrelax`

Note that this method is parameterized with an integer parameter since Xpress-Kalis offers several relaxations for each constraint. In the present case, 0 means an LP oriented relaxation and 1 means a MIP oriented relaxation.

## 6.2 User defined relaxations

Xpress-Kalis allows the user to define his own relaxation for the problem and provides several operators, functions and methods for this purpose:

- Overloaded operators for the specification of linear inequalities in a linear relaxation.
- The method `get_linrelax(ctr: cpctr)` returns the automatic relaxation for a constraint.
- The `set_integer` method turns variables in the relaxation into discrete variables (by default all relaxation variables are considered as continuous).
- Variables can be defined either in both, CP model and relaxation, or only in the CP model, or only in the relaxation (auxiliary variables)

Auxiliary variables (of the type `cpauxvar`) are additional variables that are used only in the definition of the relaxation and not in the formulation of the CP problem. For example, they can be used to linearize non-linear constraints or to express choices in the relaxation.

The CP model will not see these variables (no propagation and no branching) except for one particular kind of auxilliary variables called *indicators*. These indicator variables are 0-1 integer variables that are linked to `cpvar` variables. There is one indicator variable per value in the domain of a `cpvar`, and the indicator takes the value 1 if and only if this `cpvar` is instantiated to the value associated with the indicator variable. Bounds on indicator variables are automatically propagated by Xpress-Kalis and reduced costs provided by the relaxation are retro-propagated to the CP variables by the means of reduced costs fixing (a kind of propagation reasoning on optimality).

Indicator variables are created and retrieved by a call to the `get_indicator` function.

The following examples show some expressions that can be used in the definition of custom relaxations:

```
 declarations
  myrelax: cplinrelax               ! A linear relaxation
  a1,a2  : cpauxvar                 ! Auxiliary variables for relaxation
  taux   : array(1..4) of cpauxvar  ! Array of auxiliary variables

  x1,x2,x3: cpvar                   ! Finite domain variables
  z       : cpfloatvar              ! CP variable with continuous domain
  CAlld   : cpctr                   ! A CP constraint
 end-declarations

! Define an 'alldifferent' constraint
 CAlld := all_different({x1,x2,x3})

! Build an automatic 'LP' oriented linear relaxation
 myrelax1 := cp_get_linrelax(0)

! Setting bounds on the auxiliary variables
 setdomain(a2,0,1)
```

```
 setdomain(a1,0.56,18.67)

! Adding linear inequalities to the relaxation
 myrelax += 3*a1       <= 3
 myrelax += a1+a2      >= 3.1
 myrelax += 2*a1-4*a2  = 3
 myrelax += a1-x1       <= 3.4
 myrelax += a1+4*a2-z <= 3
 myrelax += get_linrelax(CAlld,0)
 myrelax +=
   get_indicator(x1,1) + get_indicator(x2,1) + get_indicator(x3,1) <= 1
 myrelax += sum(i in 1..4) taux(i) = 4

! Set integrality condition for variables in the relaxation
 set_integer(myrelax,a2,true)
 set_integer(myrelax,x1,true)

! Output the resulting relaxation to the screen
 cp_show_relax(myrelax)
```

## 6.3 Usage of relaxations

Xpress-Kalis can create several distinct relaxations of a CP problem and solve them.

The optimal solution of these relaxations provides bounds for the CP branch-and-bound process and prunes the search tree with reduced costs propagation (optimality reasoning).

To solve a linear relaxation, Xpress-Kalis uses relaxation solvers (of the type `cplinrelaxsolver`) that define for the relaxation:

- An objective variable for the relaxation
- An optimization sense (either `KALIS_MINIMIZE` or `KALIS_MAXIMIZE`)
- A configuration defining when and what to do with the relaxation.
- A flag indicating whether to solve the relaxation as a pure LP problem or as a MIP.(either `KALIS_SOLVE_AS_LP` or `KALIS_SOLVE_AS_MIP`

Several predefined configurations are implemented within Xpress-Kalis:

- `KALIS_TOPNODE_RELAX_SOLVER`: This configuration solves the relaxation only at the top node and provides bounds for the objective variable.
- `KALIS_TREENODE_RELAX_SOLVER`: This configuration solves the relaxation at each node of the search tree. It provides bounds for the objective variable and performs reduced costs propagation.
- `KALIS_BILEVEL_RELAX_SOLVER`: This configuration solves the relaxation whenever all the variables (by default all the discrete variables such as `cpvar`) of a user defined set are instantiated. After solving of the relaxation, all the other variables are instantiated to their optimal value in the relaxation. The main use of the bi-level configuration is to decompose the CP model simply and automatically into a master problem and a slave problem.

The user can also take full control over the relaxation solver by the means of callbacks.

A relaxation solver is obtained by specifying three callbacks functions:

- must_relax : This function with no argument and returning a Boolean must return true whenever the users wants to solve the relaxation

- before_relax : This procedure with no argument is called just before the relaxation is performed
- after_relax(status : integer) : This procedure with one argument is called after the relaxation has been solved. The status parameter indicates whether the relaxation is optimal (0) or infeasible (1). This callback can be used, for example, to instantiate some variables to their values in the optimal solution of the relaxation.

In addition to the user-configurable relaxations, Xpress-Kalis provides a fully automated mode for using linear relaxations, enabled by the control parameter `auto_relax`.

## 6.4 Branching with relaxation

Xpress-Kalis defines predefined branching schemes and value and variable selection heuristics based on the optimal solution of a relaxation:

- `KALIS_LARGEST_REDUCED_COST` variable selection heuristic selects the variable with the largest reduced cost in the optimal solution of the relaxation used by the specified relaxation solver.
- `KALIS_NEAREST_RELAXED_VALUE` value selection heuristic selects the value in the domain of the variable that is the nearest (in L1) to the value of this variable in the optimal solution of the relaxation used by the specified relaxation solver.

Moreover, the `fix_to_relaxed` method can be called during the tree search process to instantiate all the continuous variables to their values in the optimal solution of a relaxation.

This can be useful with some specific problem structures and in combination with the `KALIS_BILEVEL_RELAX_SOLVER` configuration for the relaxation solver to obtain an automatic logical benders decomposition of the solving process.

## 6.5 A simple hybrid example

Consider the following knapsack problem with an additional non linear constraint: all-different

$$
\begin{array}{rl}
\text{minimize} & 5 \cdot x_1 + 8 \cdot x_2 + 4 \cdot x_3 \\
\textit{s. t.} & 3 \cdot x_1 + 5 \cdot x_2 + 2 \cdot x_3 \geq 30 \\
 & \textit{all-different}(x_1, x_2, x_3) \\
 & x_j \in \{1, 3, 8, 12\} \text{ for } j = 1, 2, 3
\end{array}
$$

A pure and straightforward CP approach for formulating and solving this problem is shown below:

```
model "Knapsack with side constraints"
 uses "kalis"

 declarations
  x1,x2,x3: cpvar                  ! Decision variables
  benefit : cpvar                  ! The objective to minimize
 end-declarations

! Enable output printing
 setparam("verbose_level", 1)
```

```
 ! Setting name of variables for pretty printing
  setname(x1,"x1"); setname(x2,"x2"); setname(x3,"x3")
  setname(benefit,"benefit")

 ! Set initial domains for variables
  setdomain(x1, {1,3,8,12})
  setdomain(x2, {1,3,8,12})
  setdomain(x3, {1,3,8,12})

 ! Knapsack constraint
  3*x1 + 5*x2 + 2*x3 >= 30

 ! Additional global constraint
  all_different({x1,x2,x3})

 ! Objective function
  benefit = 5*x1 + 8*x2 + 4*x3

 ! Initial propagation
  res := cp_propagate

 ! Display bounds on objective after constraint propagation
  writeln("Constraints propagation objective ", benefit)

 ! Solve the problem
  if (cp_minimize(benefit)) then
   cp_show_sol                      ! Output optimal solution to screen
  end-if

 end-model
```

The model starts by getting an automatic relaxation of the problem by a call to the function `cp_get_linrelax`. Then the relaxation is printed to the standard output with a call to the `cp_show_relax` procedure.

After this a linear relaxation solver is built with a call to the `get_linrelax_solver` method. Note that the `KALIS_TOPNODE_RELAX_SOLVER` argument passed to the method indicates that we just want to solve the linear relaxation at the top node of the search tree.

After the obtention of the linear relaxation solver, we simply add it to the search process by a call to `cp_add_linrelax_solver`. Of course, Xpress-Kalis is not limited to one relaxation so several solvers can be defined and added to the search process.

The model definition is completed by specifying a 'MIP style' branching scheme that branches first on the variables with largest reduced cost and tests first the values nearest to the optimal solution of the relaxation. The invocation ot the search and solution display remain the same as in the CP model.

This is the full hybrid model:

```
 model "Knapsack with side constraints"
  uses "kalis"

  declarations
   x1,x2,x3: cpvar                   ! Decision variables
   benefit : cpvar                   ! The objective to minimize
  end-declarations

 ! Enable output printing
  setparam("verbose_level", 1)

 ! Setting name of variables for pretty printing
  setname(x1,"x1"); setname(x2,"x2"); setname(x3,"x3")
  setname(benefit,"benefit")

 ! Set initial domains for variables
  setdomain(x1, {1,3,8,12})
```

```
 setdomain(x2, {1,3,8,12})
 setdomain(x3, {1,3,8,12})

! Knapsack constraint
 3*x1 + 5*x2 + 2*x3 >= 30

! Additional global constraint
 all_different({x1,x2,x3})

! Objective function
 benefit = 5*x1 + 8*x2 + 4*x3

! Initial propagation
 res := cp_propagate

! Display bounds on objective after constraint propagation
 writeln("Constraints propagation objective ", benefit)


 declarations
  myrelaxall: cplinrelax
 end-declarations

! Build an automatic 'LP' oriented linear relaxation
 myrelaxall:= cp_get_linrelax(0)

! Output the relaxation to the screen
 cp_show_relax(myrelaxall)

 mysolver:= get_linrelax_solver(myrelaxall, benefit, KALIS_MINIMIZE,
               KALIS_SOLVE_AS_MIP, KALIS_TOPNODE_RELAX_SOLVER)

! Define the linear relaxation
 cp_add_linrelax_solver(mysolver)

! Define a 'MIP' style branching scheme using the solution of the
! optimal relaxation
 cp_set_branching(assign_var(KALIS_LARGEST_REDUCED_COST(mysolver),
                             KALIS_NEAREST_RELAXED_VALUE(mysolver)))

! Solve the problem
 if (cp_minimize(benefit)) then
  cp_show_sol                      ! Output optimal solution to screen
 end-if

end-model
```

You will find below the list of relaxation related functions and procedure defined within Xpress-Kalis :



# II. Reference Manual

# Chapter 7
# Constants



## KALIS_FORWARD_CHECKING

**Description** Forward checking propagation type for the all_different constraint

**Type** Integer, read only

**Values** 0

**Notes** This constant is passed to the all_different constraint to specify the kind of propagation used to filter it. When KALIS_FORWARD_CHECKING is used, the filtering algorithm achieves a very simple, and fast, filtering. Although less powerful than the generalized algorithm (KALIS_GEN_ARC_CONSISTENCY) that may lead to a stronger pruning, the speed of the KALIS_FORWARD_CHECKING filtering allows the search process to explore more nodes in the same amount of time which makes the algorithm competitive for simple problems.

**See also** all_different KALIS_GEN_ARC_CONSISTENCY

## KALIS_GEN_ARC_CONSISTENCY

**Description** Generalized arc consistency propagation type for the all_different constraint

**Type** Integer, read only

**Values** 3

**Notes** This constant is passed to the all_different constraint to specify the kind of propagation used to filter it. When KALIS_GEN_ARC_CONSISTENCY is used, the filtering algorithm achieves generalized arc-consistency (cf. [Ŕ94]). Although this algorithm may filter more values than the KALIS_FORWARD_CHECKING algorithm, this additional pruning comes at the price of a computational overhead at each node that is not necessary for simple problems.

**See also** all_different KALIS_FORWARD_CHECKING

## KALIS_SLIM_UNREACHED

**Description** Type of limitation on the search tree

**Type** Integer, read only

**Values** 0

**Notes** This constant represents the value of the parameter SEARCH_LIMIT when no limitation of the search process has occurred.

**See also** KALIS_SLIM_BY_NODES KALIS_SLIM_BY_SOLUTIONS KALIS_SLIM_BY_DEPTH KALIS_SLIM_BY_TIME KALIS_SLIM_BY_BACKTRACKS

## KALIS_SLIM_BY_NODES

**Description** Type of limitation on the search tree

**Type** Integer, read only

**Values** 1

**Notes** This constant represents the value of the parameter SEARCH_LIMIT when the maximum number of nodes allowed for the search process has been reached.

**See also** KALIS_SLIM_BY_NODES KALIS_SLIM_BY_SOLUTIONS KALIS_SLIM_BY_DEPTH KALIS_SLIM_BY_TIME KALIS_SLIM_BY_BACKTRACKS

## KALIS_SLIM_BY_SOLUTIONS

**Description** Type of limitation on the search tree

**Type** Integer, read only

**Values** 2

**Notes** This constant represents the value of the parameter SEARCH_LIMIT when the maximum number of solutions to be found during the search process has been reached.

**See also** KALIS_SLIM_BY_NODES KALIS_SLIM_BY_SOLUTIONS KALIS_SLIM_BY_DEPTH KALIS_SLIM_BY_TIME KALIS_SLIM_BY_BACKTRACKS

## KALIS_SLIM_BY_DEPTH

**Description** Type of limitation on the search tree

**Type** Integer, read only

**Values** 3

**Notes** This constant represents the value of the parameter SEARCH_LIMIT when the maximum depth of the search tree has been reached.

**See also** KALIS_SLIM_BY_NODES KALIS_SLIM_BY_SOLUTIONS KALIS_SLIM_BY_DEPTH KALIS_SLIM_BY_TIME KALIS_SLIM_BY_BACKTRACKS

## KALIS_SLIM_BY_TIME

**Description** Type of limitation on the search tree

**Type** Integer, read only

**Values** 4

**Notes** This constant represents the value of the parameter SEARCH_LIMIT when the maximum computation time allowed to the search process has been reached.

**See also** KALIS_SLIM_BY_NODES KALIS_SLIM_BY_SOLUTIONS KALIS_SLIM_BY_DEPTH KALIS_SLIM_BY_TIME KALIS_SLIM_BY_BACKTRACKS

## KALIS_SLIM_BY_BACKTRACKS

**Description** Type of limitation on the search tree

**Type** Integer, read only

**Values** 5

**Notes** This constant represents the value of the parameter SEARCH_LIMIT when the maximum number of backtracks was reached during the search process and the search process was interrupted.

**See also** KALIS_SLIM_BY_NODES KALIS_SLIM_BY_SOLUTIONS KALIS_SLIM_BY_DEPTH KALIS_SLIM_BY_TIME KALIS_SLIM_BY_BACKTRACKS

## KALIS_TLIM_UNREACHED

**Description** No limitation on the optimization due to tolerance limits

**Type** Integer, read only

**Values** 0

**Notes** This constant represents the value of the parameter TOLERANCE_LIMIT when no limitation of the optimization process has occurred.

**See also** KALIS_TLIM_UNREACHED KALIS_TLIM_ABS_OPT KALIS_TLIM_REL_OPT

## KALIS_TLIM_ABS_OPT

**Description** Limitation on the optimization through absolute tolerance

**Type** Integer, read only

**Values** `1`

**Notes** This constant represents the value of the parameter `TOLERANCE_LIMIT` when the search process has been interrupted due to an absolute tolerance limit.

**See also** `KALIS_TLIM_UNREACHED` `KALIS_TLIM_ABS_OPT` `KALIS_TLIM_REL_OPT`

## KALIS_TLIM_REL_OPT

**Description** Limitation on the optimization through relative tolerance

**Type** Integer, read only

**Values** `2`

**Notes** This constant represents the value of the parameter `TOLERANCE_LIMIT` when the search process has been interrupted due to a relative tolerance limit

**See also** `KALIS_TLIM_UNREACHED` `KALIS_TLIM_ABS_OPT`

## KALIS_INPUT_ORDER

**Description** Input Order variable selection heuristic

**Type** String, read only

**Values** `*a`

**Notes** Passes this constant to the constructor of branching schemes (for example assign_var) to specify the variable selection heuristic. The input order heuristic selects non-instantiated variables with the smallest index for indexed containers and in the order of iteration for ordered containers such as lists and arrays.

**See also** `KALIS_MAX_DEGREE` `KALIS_LARGEST_MIN` `KALIS_LARGEST_MAX` `KALIS_MAXREGRET_LB` `KALIS_MAXREGRET_UB` `KALIS_RANDOM_VARIABLE` `KALIS_SDOMDEG_RATIO` `KALIS_SMALLEST_DOMAIN` `KALIS_SMALLEST_MAX` `KALIS_SMALLEST_MIN`

## KALIS_MAX_DEGREE

**Description** Maximum constraint graph degree variable selection heuristic

**Type** String, read only

**Values** `*b`

**Notes** Passes this constant to the constructor of branching schemes (for example assign_var) to specify the variable selection heuristic. The max degree heuristic selects non-instantiated variables with the largest degree in the constraint graph (*i.e.*, that are involved in the maximum number of different constraints).

**See also** KALIS_INPUT_ORDER KALIS_LARGEST_MIN KALIS_LARGEST_MAX KALIS_MAXREGRET_LB KALIS_MAXREGRET_UB KALIS_RANDOM_VARIABLE KALIS_SDOMDEG_RATIO KALIS_SMALLEST_DOMAIN KALIS_SMALLEST_MAX KALIS_SMALLEST_MIN

---

## KALIS_LARGEST_MIN

---

**Description** Largest minimum variable selection heuristic

**Type** String, read only

**Values** `*c`

**Notes** Passes this constant to the constructor of branching schemes (for example assign_var) to specify the variable selection heuristic. The largest min heuristic selects non-instantiated variables with the largest lower bound.

**See also** KALIS_INPUT_ORDER KALIS_MAX_DEGREE KALIS_LARGEST_MAX KALIS_MAXREGRET_LB KALIS_MAXREGRET_UB KALIS_RANDOM_VARIABLE KALIS_SDOMDEG_RATIO KALIS_SMALLEST_DOMAIN KALIS_SMALLEST_MAX KALIS_SMALLEST_MIN

---

## KALIS_LARGEST_MAX

---

**Description** Largest maximum variable selection heuristic

**Type** String, read only

**Values** `*d`

**Notes** Passes this constant to the constructor of branching schemes (for example assign_var) to specify the variable selection heuristic. The largest maximum heuristic selects non-instantiated variables with the largest upper bound.

**See also** KALIS_INPUT_ORDER KALIS_MAX_DEGREE KALIS_LARGEST_MIN KALIS_MAXREGRET_LB KALIS_MAXREGRET_UB KALIS_RANDOM_VARIABLE KALIS_SDOMDEG_RATIO KALIS_SMALLEST_DOMAIN KALIS_SMALLEST_MAX KALIS_SMALLEST_MIN

## KALIS_MAXREGRET_LB

**Description** Maximum regret on the lower bound variable selection heuristic

**Type** String, read only

**Values** `*e`

**Notes** Passes this constant to the constructor of branching schemes (for example assign_var) to specify the variable selection heuristic. This variable selection will select the variable maximizing the distance between its lower bound and its second-smallest value.

**See also** KALIS_INPUT_ORDER KALIS_MAX_DEGREE KALIS_LARGEST_MIN KALIS_LARGEST_MAX KALIS_MAXREGRET_UB KALIS_RANDOM_VARIABLE KALIS_SDOMDEG_RATIO KALIS_SMALLEST_DOMAIN KALIS_SMALLEST_MAX KALIS_SMALLEST_MIN

## KALIS_MAXREGRET_UB

**Description** Maximum regret on the upper bound variable selection heuristic

**Type** String, read only

**Values** `*f`

**Notes** Passes this constant to the constructor of branching schemes (for example assign_var) to specify the variable selection heuristic. This variable selection will select the variable maximizing the distance between its upper bound and the second-largest value.

**See also** KALIS_INPUT_ORDER KALIS_MAX_DEGREE KALIS_LARGEST_MIN KALIS_LARGEST_MAX KALIS_MAXREGRET_LB KALIS_RANDOM_VARIABLE KALIS_SDOMDEG_RATIO KALIS_SMALLEST_DOMAIN KALIS_SMALLEST_MAX KALIS_SMALLEST_MIN

## KALIS_RANDOM_VARIABLE

**Description** Random variable selection heuristic

**Type** String, read only

**Values** `*g`

**Notes** Passes this constant to the constructor of branching schemes (for example assign_var) to specify the variable selection heuristic. The random variable heuristic selects non-instantiated variables in a random order.

**See also** KALIS_INPUT_ORDER KALIS_MAX_DEGREE KALIS_LARGEST_MIN KALIS_LARGEST_MAX KALIS_MAXREGRET_LB KALIS_MAXREGRET_UB KALIS_SDOMDEG_RATIO KALIS_SMALLEST_DOMAIN KALIS_SMALLEST_MAX KALIS_SMALLEST_MIN

## KALIS_SDOMDEG_RATIO

**Description** Smallest domain size to degree ratio variable selection heuristic.

**Type** String, read only

**Values** `*h`

**Notes** Passes this constant to the constructor of branching schemes (for example assign_var) to specify the variable selection heuristic. This heuristic selects the variable having the smallest domain size to degree ratio. The degree of a variable is defined as the number of constraints using this variable.

**See also** KALIS_INPUT_ORDER KALIS_MAX_DEGREE KALIS_LARGEST_MIN KALIS_LARGEST_MAX KALIS_MAXREGRET_LB KALIS_MAXREGRET_UB KALIS_RANDOM_VARIABLE KALIS_SMALLEST_DOMAIN KALIS_SMALLEST_MAX KALIS_SMALLEST_MIN

## KALIS_SMALLEST_DOMAIN

**Description** Smallest domain variable selection heuristic (finite domain and continuous variables)

**Type** String, read only

**Values** `*i`

**Notes** Passes this constant to the constructor of branching schemes (for example assign_var) to specify the variable selection heuristic. The smallest domain heuristic selects non instantiated variables with the smallest domain size (number of distinct values in the domain).

**See also** KALIS_INPUT_ORDER KALIS_MAX_DEGREE KALIS_LARGEST_MIN KALIS_LARGEST_MAX KALIS_MAXREGRET_LB KALIS_MAXREGRET_UB KALIS_RANDOM_VARIABLE KALIS_SDOMDEG_RATIO KALIS_SMALLEST_MAX KALIS_SMALLEST_MIN KALIS_WIDEST_DOMAIN

## KALIS_SMALLEST_MAX

**Description** Smallest maximum variable selection heuristic

**Type** String, read only

**Values** `*j`

**Notes** Passes this constant to the constructor of branching schemes (for example assign_var) to specify the variable selection heuristic. The smallest maximum heuristic selects non instantiated variables with the smallest upper bound.

**See also** KALIS_INPUT_ORDER KALIS_MAX_DEGREE KALIS_LARGEST_MIN KALIS_LARGEST_MAX KALIS_MAXREGRET_LB KALIS_MAXREGRET_UB KALIS_RANDOM_VARIABLE KALIS_SDOMDEG_RATIO KALIS_SMALLEST_DOMAIN KALIS_SMALLEST_MIN

## KALIS_SMALLEST_MIN

**Description** Smallest minimum variable selection heuristic

**Type** String, read only

**Values** `*k`

**Notes** Passes this constant to the constructor of branching schemes (for example assign_var) to specify the variable selection heuristic. The smallest mininimum heuristic selects non instantiated variables with the smallest lower bound.

**See also** KALIS_INPUT_ORDER KALIS_MAX_DEGREE KALIS_LARGEST_MIN KALIS_LARGEST_MAX KALIS_MAXREGRET_LB KALIS_MAXREGRET_UB KALIS_RANDOM_VARIABLE KALIS_SDOMDEG_RATIO KALIS_SMALLEST_DOMAIN KALIS_SMALLEST_MAX

## KALIS_WIDEST_DOMAIN

**Description** Widest domain variable selection heuristic (continuous variables)

**Type** String, read only

**Values** `*l`

**Notes** Passes this constant to the constructor of branching schemes for continuous decision variables (split_domain) to specify the variable selection heuristic. The widest domain heuristic selects non instantiated variables with the largest value interval.

**See also** KALIS_INPUT_ORDER KALIS_MAX_DEGREE KALIS_LARGEST_MIN KALIS_LARGEST_MAX KALIS_MAXREGRET_LB KALIS_MAXREGRET_UB KALIS_RANDOM_VARIABLE KALIS_SDOMDEG_RATIO KALIS_SMALLEST_DOMAIN KALIS_SMALLEST_MAX KALIS_SMALLEST_MIN

## KALIS_MAX_TO_MIN

**Description** Maximum to minimum value selection heuristic

**Type** String, read only

**Values** `+1`

**Notes** Passes this constant to the constructor of branching schemes (for example assign_var) to specify the value selection heuristic. The max to min heuristic selects values in decreasing order.

**See also** KALIS_MIN_TO_MAX KALIS_MIDDLE_VALUE KALIS_NEAREST_VALUE KALIS_RANDOM_VALUE

## KALIS_MIN_TO_MAX

**Description** Minimum to maximum value selection heuristic

**Type** String, read only

**Values** `+2`

**Notes** Passes this constant to the constructor of branching schemes (for example assign_var) to specify the value selection heuristic. The min to max heuristic selects values in increasing order.

**See also** `KALIS_MAX_TO_MIN` `KALIS_MIDDLE_VALUE` `KALIS_NEAREST_VALUE` `KALIS_RANDOM_VALUE`

## KALIS_MIDDLE_VALUE

**Description** Middle value selection heuristic

**Type** String, read only

**Values** `+3`

**Notes** Passes this constant to the constructor of branching schemes (for example assign_var) to specify the value selection heuristic. The middle value heuristic selects the value in the domain of a variable that minimizes the distance to the median value of the domain.

**See also** `KALIS_MAX_TO_MIN` `KALIS_MIN_TO_MAX` `KALIS_NEAREST_VALUE` `KALIS_RANDOM_VALUE`

## KALIS_NEAREST_VALUE

**Description** Nearest to target value selection heuristic

**Type** String, read only

**Values** `+4`

**Notes** Passes this constant to the constructor of branching schemes (for example assign_var) to specify the value selection heuristic. The nearest value heuristic selects the value in the domain of a variable that minimizes the distance to the target value of the variable.

**See also** `KALIS_MAX_TO_MIN` `KALIS_MIN_TO_MAX` `KALIS_MIDDLE_VALUE` `KALIS_RANDOM_VALUE`

## KALIS_RANDOM_VALUE

**Description** Random value selection heuristic

**Type** String, read only

**Values** `+5`

**Notes** Passes this constant to the constructor of branching schemes (for example assign_var) to specify the value selection heuristic. The random value heuristic selects a random value in the domain of a variable.

**See also** `KALIS_MAX_TO_MIN` `KALIS_MIN_TO_MAX` `KALIS_MIDDLE_VALUE` `KALIS_NEAREST_VALUE`

## KALIS_COPYRIGHT

**Description** Xpress-Kalis copyright information

**Type** String, read only

**Values** `(c) Copyrights Artelys S.A. 2000-2009`

## KALIS_UNARY_RESOURCE

**Description** Unary resource

**Type** Integer, read only

**Values** `0`

**Notes** Passes this constant to the set_resource_attributes method to specify a unary resource (a resource that can be used only by one task at a time).

**See also** `KALIS_DISCRETE_RESOURCE`

## KALIS_DISCRETE_RESOURCE

**Description** Discrete resource

**Type** Integer, read only

**Values** `1`

**Notes** Passes this constant to the set_resource_attributes function to specify a discrete resource (a resource than can be used by several tasks at the same time).

**See also** `KALIS_UNARY_RESOURCE`

## KALIS_SMALLEST_ECT

**Description** Smallest Earliest Completion time task selection heuristic

**Type** String, read only

**Values** `$1`

**Notes** Passes this constant to the constructor of task_serialize to specify the task selection heuristic.

**See also** `KALIS_SMALLEST_ECT KALIS_SMALLEST_EST KALIS_SMALLEST_LCT KALIS_SMALLEST_LST KALIS_LARGEST_ECT KALIS_LARGEST_EST KALIS_LARGEST_LCT KALIS_LARGEST_LST`

## KALIS_SMALLEST_EST

**Description** Smallest Earliest Start time task selection heuristic

**Type** String, read only

**Values** `$2`

**Notes** Passes this constant to the constructor of task_serialize to specify the task selection heuristic.

**See also** `KALIS_SMALLEST_ECT KALIS_SMALLEST_EST KALIS_SMALLEST_LCT KALIS_SMALLEST_LST KALIS_LARGEST_ECT KALIS_LARGEST_EST KALIS_LARGEST_LCT KALIS_LARGEST_LST`

## KALIS_SMALLEST_LCT

**Description** Smallest Latest Completion time task selection heuristic

**Type** String, read only

**Values** `$3`

**Notes** Passes this constant to the constructor of task_serialize to specify the task selection heuristic.

**See also** `KALIS_SMALLEST_ECT KALIS_SMALLEST_EST KALIS_SMALLEST_LCT KALIS_SMALLEST_LST KALIS_LARGEST_ECT KALIS_LARGEST_EST KALIS_LARGEST_LCT KALIS_LARGEST_LST`

## KALIS_SMALLEST_LST

**Description** Smallest Latest Start time task selection heuristic

**Type** String, read only

**Values** `$4`

**Notes** Passes this constant to the constructor of task_serialize to specify the task selection heuristic.

**See also** `KALIS_SMALLEST_ECT` `KALIS_SMALLEST_EST` `KALIS_SMALLEST_LCT` `KALIS_SMALLEST_LST` `KALIS_LARGEST_ECT` `KALIS_LARGEST_EST` `KALIS_LARGEST_LCT` `KALIS_LARGEST_LST`

## KALIS_LARGEST_ECT

**Description** Largest Earliest Completion time task selection heuristic

**Type** String, read only

**Values** `$5`

**Notes** Passes this constant to the constructor of task_serialize to specify the task selection heuristic.

**See also** `KALIS_SMALLEST_ECT` `KALIS_SMALLEST_EST` `KALIS_SMALLEST_LCT` `KALIS_SMALLEST_LST` `KALIS_LARGEST_ECT` `KALIS_LARGEST_EST` `KALIS_LARGEST_LCT` `KALIS_LARGEST_LST`

## KALIS_LARGEST_EST

**Description** Largest Earliest Start time task selection heuristic

**Type** String, read only

**Values** `$6`

**Notes** Passes this constant to the constructor of task_serialize to specify the task selection heuristic.

**See also** `KALIS_SMALLEST_ECT` `KALIS_SMALLEST_EST` `KALIS_SMALLEST_LCT` `KALIS_SMALLEST_LST` `KALIS_LARGEST_ECT` `KALIS_LARGEST_EST` `KALIS_LARGEST_LCT` `KALIS_LARGEST_LST`

## KALIS_LARGEST_LCT

**Description** Largest Latest Completion time task selection heuristic

**Type** String, read only

**Values** `$7`

**Notes** Passes this constant to the constructor of task_serialize to specify the task selection heuristic.

**See also** KALIS_SMALLEST_ECT KALIS_SMALLEST_EST KALIS_SMALLEST_LCT KALIS_SMALLEST_LST KALIS_LARGEST_ECT KALIS_LARGEST_EST KALIS_LARGEST_LCT KALIS_LARGEST_LST

## KALIS_LARGEST_LST

**Description** Largest Latest Start time task selection heuristic

**Type** String, read only

**Values** `$8`

**Notes** Passes this constant to the constructor of task_serialize to specify the task selection heuristic.

**See also** KALIS_SMALLEST_ECT KALIS_SMALLEST_EST KALIS_SMALLEST_LCT KALIS_SMALLEST_LST KALIS_LARGEST_ECT KALIS_LARGEST_EST KALIS_LARGEST_LCT KALIS_LARGEST_LST

## KALIS_TASK_INPUT_ORDER

**Description** Input order task selection heuristic

**Type** String, read only

**Values** `$9`

**Notes** Passes this constant to the constructor of task_serialize to specify the task selection heuristic.

**See also** KALIS_TASK_RANDOM_ORDER KALIS_SMALLEST_ECT KALIS_SMALLEST_EST KALIS_SMALLEST_LCT KALIS_SMALLEST_LST KALIS_LARGEST_ECT KALIS_LARGEST_EST KALIS_LARGEST_LCT KALIS_LARGEST_LST

## KALIS_TASK_RANDOM_ORDER

**Description** Random order task selection heuristic

**Type** String, read only

**Values** `$a`

**Notes** Passes this constant to the constructor of task_serialize to specify the task selection heuristic.

**See also** KALIS_TASK_INPUT_ORDER KALIS_SMALLEST_ECT KALIS_SMALLEST_EST KALIS_SMALLEST_LCT KALIS_SMALLEST_LST KALIS_LARGEST_ECT KALIS_LARGEST_EST KALIS_LARGEST_LCT KALIS_LARGEST_LST

## KALIS_DISJ_INPUT_ORDER

**Description** Input order disjunction selection heuristic

**Type** String, read only

**Values** `%0`

**Notes** Passes this constant to the constructor of settle_disjunction or probe_settle_disjunction to specify the disjunction selection heuristic.

**See also** KALIS_DISJ_PRIORITY_ORDER

## KALIS_DISJ_PRIORITY_ORDER

**Description** Input order disjunction selection heuristic

**Type** String, read only

**Values** `%1`

**Notes** Passes this constant to the constructor of settle_disjunction or probe_settle_disjunction to specify the disjunction selection heuristic.

**See also** KALIS_DISJ_INPUT_ORDER

## KALIS_TIMETABLING

**Description** Timetabling propagation type for resource constraints

**Type** Integer, read only

**Values** `1`

**Notes** This constant is passed to the `set_resource_attributes` function to specify the kind of propagation to be used for filtering the resource constraint. The KALIS_TIMETABLING filtering algorithm achieves a very simple and fast filtering. Although less powerful than the algorithms KALIS_DISJUNCTIONS (unary resources only) and KALIS_TASK_INTERVALS that may lead to a stronger pruning, the speed of the KALIS_TIMETABLING filtering allows the search process to explore more nodes in the same amount of time which makes the algorithm competitive for simple problems and also for very large problems where the computational overhead of other filtering algorithms is prohibitive.

**See also** `KALIS_TASK_INTERVALS` `KALIS_DISJUNCTIONS` `KALIS_EDGE_FINDING`

## KALIS_TASK_INTERVALS

**Description** Task intervals propagation type for resource constraints

**Type** Integer, read only

**Values** `2`

**Notes** This constant is passed to the `set_resource_attributes` procedure to specify the type of propagation to be used for filtering the resource constraint. The KALIS_TASK_INTERVALS filtering algorithm achieves a very strong and relatively slow filtering. Although more powerful than the simple algorithm (KALIS_TIMETABLING), the computational cost of the KALIS_TASK_INTERVALS filtering makes it competitive for medium sized hard problems but is prohibitive for large problems with many tasks per resource (cf. [CL94a], [CL94b]).

**See also** `KALIS_TIMETABLING` `KALIS_DISJUNCTIONS` `KALIS_EDGE_FINDING`

## KALIS_DISJUNCTIONS

**Description** Disjunctions propagation type for unary resource constraints

**Type** Integer, read only

**Values** `4`

**Notes** This constant is passed to the `set_resource_attributes` procedure to specify the type of propagation to be used for filtering the resource constraint for unary resources. With KALIS_DISJUNCTIONS the resource constraint will be implemented as n*(n-1)/2 disjunctions between pairs of tasks. This algorithm is more powerful than the KALIS_TIMETABLING algorithm but less powerful than the algorithm KALIS_TASK_INTERVALS that may lead to a stronger pruning at the cost of additional computation overhead. This algorithm is generally competitive for small to medium size problems where the number of tasks using the resource is not overly large.

**See also** `KALIS_TASK_INTERVALS` `KALIS_TIMETABLING` `KALIS_EDGE_FINDING`

## KALIS_EDGE_FINDING

**Description** Tasks Interval + Edge finding propagation type for discrete resource constraints

**Type** Integer, read only

**Values** `4`

**Notes** This constant is passed to the `set_resource_attributes` procedure to specify the kind of propagation used to filter the resource constraint. When KALIS_EDGE_FINDING is used, the resource constraint will add Edge finding propagation rules to the Tasks Interval propgation scheme. This algorithm is more powerful than KALIS_TASK_INTERVALS algorithm and may lead to a stronger pruning at the cost of additional computation overhead. This algorithm is generally competitive for small to medium size problems where the number of tasks using the resource is not too large (cf. [LP96], [MVH08]).

**See also** `KALIS_TASK_INTERVALS` `KALIS_TIMETABLING` `KALIS_DISJUNCTIONS`

## KALIS_INITIAL_SOLUTION

**Description** Schedule search strategy choice: heuristic solution

**Type** Integer, read only

**Values** `0`

**Notes** This constant is passed to the cp_set_schedule_strategy function to specify the phase of the algorithm. KALIS_INITIAL_SOLUTION denotes the first phase of the algorithm and KALIS_OPTIMAL_SOLUTION selects the second phase of the algorithm.

**See also** `KALIS_OPTIMAL_SOLUTION` `cp_schedule`

## KALIS_OPTIMAL_SOLUTION

**Description** Schedule search strategy choice: improving bound and prove optimality

**Type** Integer, read only

**Values** `1`

**Notes** This constant is passed to the cp_set_schedule_strategy function to specify the phase of the algorithm. KALIS_INITIAL_SOLUTION denotes the first phase of the algorithm and KALIS_OPTIMAL_SOLUTION selects the second phase of the algorithm.

**See also** `KALIS_INITIAL_SOLUTION` `cp_schedule`

## KALIS_RESET_PARAMS_ALL

**Description** Group parameter choice for all parameters

**Type** Integer, read only

**Values** 0

**Notes** This constant is passed to the cp_reset_params function to specify the group of control parameters. KALIS_RESET_PARAMS_ALL reset all variables and strategy parameters :

- DEFAULT_LB
- DEFAULT_UB
- DEFAULT_CONTINUOUS_LB
- DEFAULT_CONTINUOUS_UB
- DEFAULT_PRECISION_VALUE
- DEFAULT_PRECISION_RELATIVITY
- AUTO_CREATES_VAR
- AUTO_PROPAGATE
- OPTIMIZE_WITH_RESTART
- DICHOTOMIC_OBJ_SEARCH
- USE_3B_CONSISTENCY
- VERBOSE_LEVEL
- MAX_NODES
- MAX_SOLUTIONS
- MAX_DEPTH
- OPT_ABS_TOLERANCE
- OPT_REL_TOLERANCE
- MAX_BACKTRACKS
- MAX_COMPUTATION_TIME
- MAX_NODES_BETWEEN_SOLUTIONS

## KALIS_RESET_VAR_BOUNDS

**Description** Group parameter choice for variable bounds

**Type** Integer, read only

**Values** 1

**Notes** This constant is passed to the set_cp_reset_params function to specify the group of control parameters. KALIS_RESET_VAR_BOUNDSS reset bounds of discrete and continuous variables :

- DEFAULT_LB
- DEFAULT_UB
- DEFAULT_CONTINUOUS_LB
- DEFAULT_CONTINUOUS_UB

## KALIS_RESET_VAR_PRECISION

**Description** Group parameter choice for variable precisions

**Type** Integer, read only

**Values** 2

**Notes** This constant is passed to the cp_reset_params function to specify the group of control parameters. KALIS_RESET_VAR_PRECISION reset the precision for continuous variables :

- DEFAULT_PRECISION_VALUE
- DEFAULT_PRECISION_RELATIVITY

## KALIS_RESET_OPT_PARAMS

**Description** Group parameter choice for strategy optimisation

**Type** Integer, read only

**Values** 3

**Notes** This constant is passed to the cp_reset_params function to specify the group of control parameters. KALIS_RESET_OPT_PARAMS reset mechanisms of search :

- AUTO_CREATES_VAR
- AUTO_PROPAGATE
- OPTIMIZE_WITH_RESTART
- DICHOTOMIC_OBJ_SEARCH
- USE_3B_CONSISTENCY

## KALIS_RESET_SEARCH_PARAMS

**Description** Group parameter choice for strategy properties

**Type** Integer, read only

**Values** 4

**Notes** This constant is passed to the cp_reset_params function to specify the group of control parameters. KALIS_RESET_SEARCH_PARAMS reset properties of search :

- VERBOSE_LEVEL
- MAX_NODES
- MAX_SOLUTIONS
- MAX_DEPTH
- OPT_ABS_TOLERANCE

- OPT_REL_TOLERANCE
- MAX_BACKTRACKS
- MAX_COMPUTATION_TIME
- MAX_NODES_BETWEEN_SOLUTIONS

## KALIS_TOPNODE_RELAX_SOLVER

**Description** Top node relaxation solver configuration

**Type** Integer, read only

**Values** `200`

**Notes** This constant is passed to the get_linrelax_solver function to specify the predifined relaxation solver configuration. In this configuration, the relaxation is solved only once at the top node of the search tree

**See also** KALIS_BILEVEL_RELAX_SOLVER KALIS_TREENODE_RELAX_SOLVER

## KALIS_TREENODE_RELAX_SOLVER

**Description** Tree node relaxation solver configuration

**Type** Integer, read only

**Values** `201`

**Notes** This constant is passed to the get_linrelax_solver function to specify the predifined relaxation solver configuration. In this configuration, the relaxation is solved at all nodes (except the top node) of the search tree

**See also** KALIS_TOPNODE_RELAX_SOLVER KALIS_BILEVEL_RELAX_SOLVER

## KALIS_BILEVEL_RELAX_SOLVER

**Description** Bilevel node relaxation solver configuration

**Type** Integer, read only

**Values** `202`

**Notes** This constant is passed to the get_linrelax_solver function to specify the predifined relaxation solver configuration. In this configuration, the relaxation is solved only when a user defined set of variables are instantiated (by default all the cpfloatvars)

**See also** KALIS_TOPNODE_RELAX_SOLVER KALIS_TREENODE_RELAX_SOLVER

## KALIS_LINEAR_CONSTRAINTS

**Description** Set of linear constraints

**Type** Integer, read only

**Values** `0`

**Notes** This constant is passed to the `cp_get_linrelax` function to specify the phase of the algorithm.

**See also** `KALIS_NON_LINEAR_CONSTRAINTS` `KALIS_LOGICAL_CONSTRAINTS` `KALIS_DISTANCE_CONSTRAINTS` `KALIS_ALL_CONSTRAINTS` `cp_get_linrelax`

## KALIS_NON_LINEAR_CONSTRAINTS

**Description** Set of non linear constraints

**Type** Integer, read only

**Values** `1`

**Notes** This constant is passed to the `cp_get_linrelax` function to specify the phase of the algorithm.

**See also** `KALIS_LINEAR_CONSTRAINTS` `KALIS_LOGICAL_CONSTRAINTS` `KALIS_DISTANCE_CONSTRAINTS` `KALIS_ALL_CONSTRAINTS` `cp_get_linrelax`

## KALIS_LOGICAL_CONSTRAINTS

**Description** Set of logical constraints

**Type** Integer, read only

**Values** `2`

**Notes** This constant is passed to the `cp_get_linrelax` function to specify the phase of the algorithm.

**See also** `KALIS_LINEAR_CONSTRAINTS` `KALIS_NON_LINEAR_CONSTRAINTS` `KALIS_DISTANCE_CONSTRAINTS` `KALIS_ALL_CONSTRAINTS` `cp_get_linrelax`

## KALIS_DISTANCE_CONSTRAINTS

**Description** Set of the distances constraints

**Type** Integer, read only

**Values** 3

**Notes** This constant is passed to the `cp_get_linrelax` function to specify the phase of the algorithm.

**See also** `KALIS_LINEAR_CONSTRAINTS` `KALIS_NON_LINEAR_CONSTRAINTS` `KALIS_LOGICAL_CONSTRAINTS` `KALIS_ALL_CONSTRAINTS` `cp_get_linrelax`

## KALIS_ALL_CONSTRAINTS

**Description** Set of all the constraints

**Type** Integer, read only

**Values** 4

**Notes** This constant is passed to the `cp_get_linrelax` function to specify the phase of the algorithm.

**See also** `KALIS_LINEAR_CONSTRAINTS` `KALIS_NON_LINEAR_CONSTRAINTS` `KALIS_LOGICAL_CONSTRAINTS` `KALIS_DISTANCE_CONSTRAINTS` `cp_get_linrelax`

## KALIS_MINIMIZE

**Description** Minimize objective in linear relaxation

**Type** Integer, read only

**Values** 100

**Notes** This constant is passed to the cp_set_linrelax function to specify the sense of objective

## KALIS_MAXIMIZE

**Description** Maximize objective in linear relaxation

**Type** Integer, read only

**Values** 101

**Notes** This constant is passed to the cp_set_linrelax function to specify the sense of objective

## KALIS_SOLVE_AS_LP

**Description** Use LP relaxation

**Type** Integer, read only

**Values** `10`

**Notes** This constant is passed to the get_linrelax_solver function to specify the type of method use

## KALIS_SOLVE_AS_MIP

**Description** Use MIP relaxation

**Type** Integer, read only

**Values** `11`

**Notes** This constant is passed to the get_linrelax_solver function to specify the type of method use

# Chapter 8

# Parameters



| | | |
|---|---|---|
| SEARCH_LIMIT | Search limit reached | p. 55 |
| TOLERANCE_LIMIT | Tolerance limit reached | p. 56 |
| USE_3B_CONSISTENCY | Activates 3B consistency for continuous variables | p. 61 |
| VERBOSE_LEVEL | Verbosity level of Xpress-Kalis | p. 61 |

## DEFAULT_LB

**Description** Default lower bound for finite domain variables

**Type** Integer, read/write

**Values** `-10000` default value

**Notes** Sets the default lower bound for the initial domain of enumerated domain decision variables.

**See also** DEFAULT_UB getlb

## DEFAULT_UB

**Description** Default upper bound for finite domain variables

**Type** Integer, read/write

**Values** `+10000` default value

**Notes** Sets the default upper bound for the initial domain of enumerated domain decision variables.

**See also** DEFAULT_LB getub

## AUTO_PROPAGATE

**Description** Propagates automatically

**Type** Boolean, read/write

**Values** `true` default value

**Notes** Enables propagating constraints instead of posting them or searching for solutions. Note that domain definition of decision variables is always taken into account irrespective of whether this control is on or off.

**See also** cp_propagate cp_post

## OPTIMIZE_WITH_RESTART

**Description** Decides whether to restart the search after each solution or to continue search from the present point with the new bound on the objective.

**Type** Boolean, read/write

**Values** `false` default value (no restart)

**Affects routines** `cp_minimize` `cp_maximize`

## NODES

**Description** Counter for number of nodes

**Type** Integer, read only

**Notes** Current number of nodes explored by the branch and bound search. This parameter does not work with `cp_schedule`.

**See also** `MAX_NODES` `DEPTH` `BACKTRACKS` `COMPUTATION_TIME`

## DEPTH

**Description** Depth of tree search

**Type** Integer, read only

**Notes** Maximal depth of the search tree reached by the branch and bound search. This parameter does not work with `cp_schedule`.

**See also** `MAX_DEPTH` `NODES` `BACKTRACKS` `COMPUTATION_TIME`

## SEARCH_LIMIT

**Description** Search limit reached

**Type** Integer, read only

**Notes** Active search limit on the search process if any

**See also** `KALIS_SLIM_UNREACHED` `KALIS_SLIM_BY_NODES` `KALIS_SLIM_BY_SOLUTIONS` `KALIS_SLIM_BY_DEPTH` `KALIS_SLIM_BY_TIME` `KALIS_SLIM_BY_BACKTRACKS`

## TOLERANCE_LIMIT

**Description** Tolerance limit reached

**Type** Integer, read only

**Notes** Active tolerance limit on the search process if any

**See also** KALIS_TLIM_UNREACHED KALIS_TLIM_ABS_OPT KALIS_TLIM_REL_OPT OPT_REL_TOLERANCE OPT_ABS_TOLERANCE

## BACKTRACKS

**Description** Number of backtracks

**Type** Integer, read only

**Notes** Current number of backtracks that occurred during the branch and bound search.

**See also** MAX_SOLUTIONS MAX_NODES MAX_COMPUTATION_TIME MAX_DEPTH MAX_BACKTRACKS MAX_NODES_BETWEEN_SOLUTIONS

## COMPUTATION_TIME

**Description** Computation time

**Type** Double, read only

**Notes** Current computation time (in seconds) of the search process.

**See also** MAX_SOLUTIONS MAX_NODES MAX_COMPUTATION_TIME MAX_DEPTH MAX_BACKTRACKS MAX_NODES_BETWEEN_SOLUTIONS

## MAX_NODES

**Description** Maximum number of nodes

**Type** Integer, read/write

**Values** `-1` default value (no limit)

**Notes** Limits the number of nodes explored during the branch and bound tree search.

**Affects routines** `cp_find_next_sol` `cp_minimize` `cp_maximize`

**See also** NODES MAX_SOLUTIONS MAX_COMPUTATION_TIME MAX_DEPTH MAX_BACKTRACKS MAX_NODES_BETWEEN_SOLUTIONS

## MAX_SOLUTIONS

**Description** Maximum number of solutions

**Type** Integer, read/write

**Values** `-1` default value (no limit)

**Notes** Limits the number of solutions to be found during the branch and bound tree search.

**Affects routines** `cp_find_next_sol` `cp_minimize` `cp_maximize`

**See also** `MAX_NODES` `MAX_COMPUTATION_TIME` `MAX_DEPTH` `MAX_BACKTRACKS` `MAX_NODES_BETWEEN_SOLUTIONS`

## MAX_DEPTH

**Description** Maximum depth

**Type** Integer, read/write

**Values** `-1` default value (no limit)

`n>0` maximum depth limited to `n` levels.

**Notes** Limits the depth of the search tree during the branch and bound search. This parameter does not work with `cp_schedule`.

**Affects routines** `cp_find_next_sol` `cp_minimize` `cp_maximize`

**See also** `DEPTH` `MAX_SOLUTIONS` `MAX_NODES` `MAX_COMPUTATION_TIME` `MAX_BACKTRACKS` `MAX_NODES_BETWEEN_SOLUTIONS`

## MAX_BACKTRACKS

**Description** Maximum number of backtracks

**Type** Integer, read/write

**Values** `-1` default value (no limit)

**Notes** Limits the number of backtracks that can occur during the search process before termination

**Affects routines** `cp_find_next_sol` `cp_minimize` `cp_maximize`

**See also** `BACKTRACKS` `MAX_SOLUTIONS` `MAX_NODES` `MAX_COMPUTATION_TIME` `MAX_DEPTH` `MAX_NODES_BETWEEN_SOLUTIONS`

## MAX_COMPUTATION_TIME

| | |
|---|---|
| **Description** | Maximum computation time |
| **Type** | Double, read/write |
| **Values** | `-1` default value (no limit) |
| **Notes** | Limits the maximum computation time (in seconds) allowed to the branch and bound |
| **Affects routines** | `cp_find_next_sol` `cp_minimize` `cp_maximize` |
| **See also** | `COMPUTATION_TIME` `MAX_SOLUTIONS` `MAX_NODES` `MAX_DEPTH` `MAX_BACKTRACKS` |

## MAX_NODES_BETWEEN_SOLUTIONS

| | |
|---|---|
| **Description** | Number of nodes between two solutions |
| **Type** | Integer, read/write |
| **Notes** | Maximum number of nodes explored between two solutions. With `cp_schedule` the limit only applies to the last phase of the solution algorithm. |
| **Affects routines** | `cp_minimize` `cp_maximize` |
| **See also** | `NODES` `MAX_NODES` `MAX_SOLUTIONS` `MAX_COMPUTATION_TIME` `MAX_DEPTH` `MAX_BACKTRACKS` |

## OPT_ABS_TOLERANCE

| | |
|---|---|
| **Description** | Absolute optimality tolerance |
| **Type** | Integer, read/write |
| **Values** | `0` default value (no tolerance) |
| **Notes** | Enables the search process to stop when the distance between the current solution and the overall optimum is ensured to be less than opt_abs_tolerance |
| **Affects routines** | `cp_minimize` `cp_maximize` |
| **See also** | `OPT_REL_TOLERANCE` |

## OPT_REL_TOLERANCE

| | |
|---|---|
| **Description** | Relative optimality tolerance |
| **Type** | Double, read/write |

| | | |
|---|---|---|
| **Values** | `0.0` | default value (no tolerance) |

**Notes** Enables the search process to stop when the relative distance between the current solution and the overall optimum solution is ensured to be less than opt_rel_tolerance

**Affects routines** `cp_minimize` `cp_maximize`

**See also** `OPT_ABS_TOLERANCE`

## CHECK_SOLUTION

**Description** Automated solution checking

**Type** Integer, read/write

**Values** `false` default value (no solution checking)

**Notes** Enables the automated checking that the solution found is really a solution

**Affects routines** `cp_find_next_sol` `cp_minimize` `cp_maximize`

## DEFAULT_CONTINUOUS_LB

**Description** Default lower bound for domains of cpfloatvar

**Type** Double, read/write

**Values** `-1000000` default value

**Notes** Sets the default lower bound for the initial domain of continuous decision variables

**See also** `DEFAULT_CONTINUOUS_UB` `getlb`

## DEFAULT_CONTINUOUS_UB

**Description** Default upper bound for domains of cpfloatvar

**Type** Double, read/write

**Values** `+1000000` default value

**Notes** Sets the default upper bound for the initial domain of continuous decision variables

**See also** `DEFAULT_CONTINUOUS_LB` `getub`

## DEFAULT_PRECISION_VALUE

| | |
|---|---|
| **Description** | Default precision for continuous variables |
| **Type** | Double, read/write |
| **Values** | `+1e-6` default value |
| **Notes** | Default precision for continuous variables |
| **See also** | `setprecision` |

## DEFAULT_PRECISION_RELATIVITY

| | |
|---|---|
| **Description** | Precision relativity for continuous variables |
| **Type** | Boolean, read/write |
| **Values** | `false` default value |
| **Notes** | Precision relativity for continuous variables |
| **See also** | `setprecision` |

## DEFAULT_SCHEDULE_HORIZ_MIN

| | |
|---|---|
| **Description** | Default minimal time horizon for schedules |
| **Type** | Integer, read/write |
| **Values** | `0` default value |
| **Notes** | Default minimal time horizon for schedules |
| **See also** | `DEFAULT_SCHEDULE_HORIZ_MAX` |

## DEFAULT_SCHEDULE_HORIZ_MAX

| | |
|---|---|
| **Description** | Default maximal time horizon for schedules |
| **Type** | Integer, read/write |
| **Values** | `10000` default value |
| **Notes** | Default maximal time horizon for schedules |
| **See also** | `DEFAULT_SCHEDULE_HORIZ_MIN` |

## DICHOTOMIC_OBJ_SEARCH

| | |
|---|---|
| **Description** | Uses a dichotomic strategy to find the optimal objective value |
| **Type** | Boolean, read/write |
| **Values** | `false` default value |
| **Notes** | Uses a dichotomic strategy to find the optimal objective value. By default the optimization algorithm imposes an amelioration constraint stating that the objective value of the solution to be found must be better than the objective value of the best solution already found. With a dichotomic optimization strategy, this constraint is replaced by a binary search tree over the objective variable domain. |
| **Affects routines** | `cp_minimize` `cp_maximize` |

## USE_3B_CONSISTENCY

| | |
|---|---|
| **Description** | Activates 3B consistency for continuous variables |
| **Type** | Boolean, read/write |
| **Values** | `true` default value |
| **Affects routines** | `cp_propagate` |

## VERBOSE_LEVEL

| | | |
|---|---|---|
| **Description** | Verbosity level of Xpress-Kalis | |
| **Type** | Integer, read/write | |
| **Values** | `0` | all output disabled |
| | `1` | enable summary output printing |
| | `2` | more detailed output |
| | `3` | debug output |

## AUTO_RELAX

| | |
|---|---|
| **Description** | Indicates whether to use linear relaxation automatically |
| **Type** | Boolean, read/write |
| **Values** | `false` default value |
| **Notes** | Enables automatic problem relaxation. |
| **See also** | `cp_propagate` `cp_post` |

# Chapter 9
# Subroutines

## 9.1 Constraints

# cplinctr

**Purpose**

Linear constraints are arithmetic constraints over decision variables. Linear constraints are defined with linear expressions combined by arithmetic operators such as =, $\neq$ , $\leq$ , and $\geq$ .
Objects of type cplinexp are linear expressions of decision variables. Typically, these objects result as intermediate objects in the definition of linear constraints.
Linear expressions of decision variables are obtained by applying the operators +, - and * to decision variables and integer values. The standard priority rules used by Mosel apply to the evaluation order of the arithmetic operators. Brackets may be used in the definition of linear expressions to change this order. The following are examples of valid linear expressions:

```
declarations
   A, B: integer
   x, y: cpvar
   z: array(1..10) of cpfloatvar
end-declarations
A*x*B
-x + 2*A*y
B*(x-y)
(abs(A) + ceil(2.9) + round(-3.4)) * x
sum(i in 1..10) z(i)
```

The following definitions are not valid for objects of type cplinexp:

```
x*y
ln(2) * x
y/3
```

### Synopsis

```
X = I with X:cpvar and I:integer
x = y with x,y:cpvar
z = r with z:cplinexp and r:real
z = x with z:cplinexp and x:cpvar
z = w with z,w:cplinexp
I = x with I:integer and x:cpvar
R = z with R:real and z:cplinexp
x = z with X:cpvar and z:cplinexp
x <>R with x:cpvar and R:real
x <>y with x,y:cpvar
z <>R with z:cplinexp and R:real
z <>x with z:cplinexp and x:cpvar
z <>w with z,w:cplinexp
I <>x with I:integer and x:cpvar
R <>z with R:real and z:cplinexp
x <>z with x:cpvar and z:cplinexp
x <= I with x:cpvar and I:integer
x <= y with x,y:cpvar
z <= R with z:cplinexp and R:real
z <= x with z:cplinexp and x:cpvar
z <= w with z,w:cplinexp
I <= x with I:integer and x:cpvar
R <= z with R:real and z:cplinexp
x <= z with x:cpvar and z:cplinexp
x <= R with x:cpfloatvar and R:real
x >= I with x:cpvar and I:integer
x >= y with x,y:cpvar
z >= R with z:cplinexp and R:real
z >= x with z:cplinexp and x:cpvar
z >= w with z,w:cplinexp
I >= x with I:integer and x:cpvar
R >= z with R:real and z:cplinexp
x >= z with x:cpvar and z:cplinexp
x >= R with x:cpfloatvar and R:real
```

### Return value

A linear constraint combining the two arguments

### Example

The following example shows how to state different kinds of linear constraints:

```
model "Linear constraints"
 uses "kalis"

 declarations
  N = 3
  R = 1..N
  x: array(R) of cpvar
  c1: cpctr
 end-declarations

 forall(i in R) do
  0 <= x(i); x(i) <= 50
  setname(x(i), "x"+i)
 end-do
```

```
! Automated post+propagation
 x(1) >= x(3) + 5
 writeln(x(1), " ", x(3))

! Named constraint (explicit post)
 c1:= x(3) >= x(2) + 10

 if cp_post(c1) then
  writeln("With constraint c1: ", x)
 else exit(1)
 end-if

! Stop automated propagation
 setparam("auto_propagate", false)

! Automated post w/o propagation
 x(2) >= 10
 writeln("new bound for x2: ", x)
 if cp_propagate then
  writeln("after propagation: ", x)
 end-if

! Minimize the value of x(1)
 if cp_minimize(x(1)) then
  write("Solution: ")
  forall(i in R) write(getsol(x(i)), " ")
  writeln
 end-if
end-model
```

### Related topics

getval

# and

### Purpose

This composite constraint states a conjunction between two constraints C1 and C2 ($C1 \wedge C2$). The satisfaction of the resulting constraint is given by the following truth table:

```
C1     C2       C1 and C2
--------------------------
false  false    false
false  true     false
true   false    false
true   true     true
```

### Synopsis

`C1 and C2`

### Arguments

| | |
|---|---|
| `C1` | the left member constraint of the conjunction |
| `C2` | the right member constraint of the conjunction |

### Return value

A conjunction constraint over C1 and C2

### Example

The following example shows how to use the conjunction constraint

```
model "Logical constraints"
 uses "kalis"

! Default bounds for all variables
 setparam("DEFAULT_LB", 0); setparam("DEFAULT_UB", 1)

 declarations
  a,b: cpvar
 end-declarations

 setname(a,"a")
 setname(b,"b")

 writeln(a,b)
 (a >= 1) and (b >= 1) or (a <= 0) and (b >= 1)

 while (cp_find_next_sol)
  writeln("a:", getsol(a), " b:", getsol(b))

end-model
```

### Related topics

`implies` `and` `or`

# or

### Purpose

This composite constraint states a disjunction between two constraints C1 and C2 ($C1 \vee C2$). The satisfaction of the resulting constraint is given by the following truth table:

```
C1     C2       C1 or C2
--------------------------
false  false    false
false  true     true
true   false    true
true   true     true
```

### Synopsis

`C1 or C2`

### Arguments

| | |
|---|---|
| `C1` | the left member constraint of the disjunction |
| `C2` | the right member constraint of the disjunction |

### Return value

A disjunction constraint over C1 and C2

### Example

The following example shows how to use the disjunction constraint

```
model "Logical constraints"
 uses "kalis"

! Default bounds for all variables
 setparam("DEFAULT_LB", 0); setparam("DEFAULT_UB", 1)

 declarations
  a,b: cpvar
 end-declarations

 setname(a,"a")
 setname(b,"b")

 writeln(a,b)
 (a >= 1) and (b >= 1) or (a <= 0) and (b >= 1)

 while (cp_find_next_sol)
  writeln("a:", getsol(a), " b:", getsol(b))

end-model
```

### Related topics

implies and or

## equiv

### Purpose

This composite constraint states an equivalence between two constraints C1 and C2 (C1 ⇔ C2), which are not individually posted. The satisfaction of the resulting constraint is given by the following truth table:

```
C1     C2       C1 equiv C2
--------------------------
false  false    true
false  true     false
true   false    false
true   true     true
```

### Synopsis

```
function equiv(C1:cpctr,C2:cpctr) :  cpctr
```

### Arguments

`C1` the left member constraint of the equivalence

`C2` the right member constraint of the equivalence

### Return value

An equivalence constraint over C1 and C2

### Example

The following example shows how to use the equivalence constraint

```
model "Logical constraints"
 uses "kalis"

! Default bounds for all variables
 setparam("DEFAULT_LB", 0); setparam("DEFAULT_UB", 5)

 declarations
  A, B, C, D, E: cpctr
  x,y,z,b: cpvar
 end-declarations

 setname(b, "b"); setname(x, "x")
 setname(y, "y"); setname(z, "z")
 b <= 1

! Definition of constraints (without posting)
 A:= x >= y + 5 + z + b
 B:= b = 1
 C:= all_different({x, y, z})    ! Cannot be used with 'equiv'
 D:= y <= z
 E:= distance(y,z) <= 2

 writeln("Original domains: ", b, " ", x, " ", y, " ", z)

! If x, y and z are all different then b equals 1 (C=>B),
! if b equals 1 then x, y and z are all different (B=>C).
 implies(C, B)
 implies(B, C)

! E<=>B: b equals 1 if and only if |y-z| <= 2
 equiv(E, B)
```

```
! A<=>D: x >= y + 5 + z + b if and only if y <= z
 equiv(A, D)

 writeln("With constraints: ", b, " ", x, " ", y, " ", z)

 while (cp_find_next_sol)
  writeln("Solution: ", b, " ", x, " ", y, " ", z)

end-model
```

### Related topics

implies and or

## implies

### Purpose

This composite constraint states an implication between two constraints C1 and C2 (C1 $\Rightarrow$ C2), which are not individually posted. The satisfaction of the resulting constraint is given by the following truth table:

```
C1     C2       C1 implies C2
--------------------------
false  false    true
false  true     true
true   false    false
true   true     true
```

### Synopsis

```
function implies(C1:cpctr, C2:cpctr) :  cpctr
```

### Arguments

| | |
|---|---|
| `C1` | the left member constraint of the implication |
| `C2` | the right member constraint of the implication |

### Return value

An implication constraint over C1 and C2

### Example

The following example shows how to use the implication constraint

```
model "Logical constraints"
 uses "kalis"

! Default bounds for all variables
 setparam("DEFAULT_LB", 0); setparam("DEFAULT_UB", 5)

 declarations
  A, B, C, D, E: cpctr
  x,y,z,b: cpvar
 end-declarations

 setname(b, "b"); setname(x, "x")
 setname(y, "y"); setname(z, "z")
 b <= 1

! Definition of constraints (without posting)
 A:= x >= y + 5 + z + b
 B:= b = 1
 C:= all_different({x, y, z})     ! Cannot be used with 'equiv'
 D:= y <= z
 E:= distance(y,z) <= 2

 writeln("Original domains: ", b, " ", x, " ", y, " ", z)

! If x, y and z are all different then b equals 1 (C=>B),
! if b equals 1 then x, y and z are all different (B=>C).
 implies(C, B)
 implies(B, C)

! E<=>B: b equals 1 if and only if |y-z| <= 2
 equiv(E, B)
```

```
! A<=>D: x >= y + 5 + z + b if and only if y <= z
 equiv(A, D)

 writeln("With constraints: ", b, " ", x, " ", y, " ", z)

 while (cp_find_next_sol)
  writeln("Solution: ", b, " ", x, " ", y, " ", z)

end-model
```

### Related topics

equiv and or

## cpnlinctr

### Purpose

Non-linear constraints are arithmetic constraints over decision variables. Non-linear constraints are defined with non-linear expressions combined by arithmetic operators such as =, $\leq$ , and $\geq$ . Non-linear expressions of decision variables have the type cpnlinexp. Typically, these objects result as intermediate objects in the definition of non-linear constraints.
Non-linear expressions of decision variables are obtained by applying the operators +, -, *, div, or functions like `ln`, `exp`, `abs` to decision variables and numeric values. The standard priority rules used by Mosel apply to the evaluation order of the arithmetic operators. Brackets may be used in the definition of non-linear expressions to change this order. The following are examples of valid non-linear expressions:

```
declarations
y: cpvar
x1,x2,x3,x4,x5: cpfloatvar
end-declarations
0.4*x3*x5 + 0.1*x3*x4 >= 10.7
x1^2 = y
exp(x3-x4)  2
ln(x5) = 1
(x1*x2^2) div (x4-x3) = 3
```

### Synopsis

```
X op v with X:cpnlinexp and v:cpfloatvar and op one of =, ≥ , ≤
X op r with X:cpnlinexp and r:realand op one of =, ≥ , ≤
X op v with X:cpnlinexp and v:cpvarand op one of =, ≥ , ≤
X op l with X:cpnlinexp and l:cplinexpand op one of =, ≥ , ≤
```

### Return value

A non-linear constraint combining the two arguments

### Example

The following example shows how to state different kinds of non-linear constraints:

```
model "Non-linear constraints"
 uses "kalis"

 parameters
  PREC =  1e-10
 end-parameters

! Setting default precision of continuous variables
 setparam("DEFAULT_PRECISION_VALUE", PREC)

 declarations
  ISET = 1..8
  x: array(ISET) of cpfloatvar
 end-declarations

 ! Setting variable names
 forall(i in ISET) x(i).name:= "x"+i

 ! Setting variable bounds
 forall(i in ISET) do
  x(i) >= -100; x(i) <= 100
 end-do
```

```
! Defining and posting non-linear constraints
x(1) + x(2)*(x(1)+x(3)) + x(4)*(x(3)+x(5)) + x(6)*(x(5)+x(7)) -
  (x(8)*((1/8)-x(7))) = 0
x(2) + x(3)*(x(1)+x(5)) + x(4)*(x(2)+x(6)) + x(5)*x(7) -
  (x(8)*((2/8)-x(6))) = 0
x(3)*(1 + x(6)) + x(4)*(x(1)+x(7)) + x(2)*x(5) -
  (x(8)*((3/8)-x(5))) = 0
x(4) + x(1)*x(5) + x(2)*x(6) + x(3)*x(7) - (x(8)*((4/8)-x(4))) = 0
x(5) + x(1)*x(6) + x(2)*x(7) - (x(8)*((5/8)-x(3))) = 0
x(6) + x(1)*x(7) - (x(8)*((6/8)-x(2))) = 0
x(7) - (x(8)*((7/8)-x(1))) = 0
sum(i in ISET) x(i) = -1

! Set the enumeration strategy
cp_set_branching(split_domain(KALIS_WIDEST_DOMAIN, KALIS_MIDDLE_VALUE,
                              x, true, 0))

! Find one solution
if (cp_find_next_sol) then
 writeln("Solution number 1" )
 cp_show_sol
 cp_show_stats
end-if

end-model
```

### Related topics

getval

# ln

### Purpose

Natural logarithm of a non-linear expression

### Synopsis

```
function ln(x:cpnlinexp) :  cpnlinexp
function ln(x:cplinexp) :  cpnlinexp
function ln(x:cpfloatvar) :  cpnlinexp
function ln(x:cpvar) :  cpnlinexp
```

### Argument

`x` Non-linear expression

### Return value

A natural logarithm constraint over a non-linear expression x: $y = \ln x$

### Related topics

`exp` `abs`

# exp

### Purpose

Exponential of a non-linear expression

### Synopsis

```
function exp(x:cpnlinexp) :  cpnlinexp
function exp(x:cplinexp) :  cpnlinexp
function exp(x:cpfloatvar) :  cpnlinexp
function exp(x:cpvar) :  cpnlinexp
```

### Argument

`x` Non-linear expression

### Return value

An exponential constraint over a non-linear expression x: $y = e^x$

### Related topics

`ln` `abs`

# distance

### Purpose

This constraint specifies the distance between two variables.

### Synopsis

```
function distance(x:cpvar, y:cpvar) :  0cpabs
```

### Argument

`x,y` finite domain variables

### Return value

An absolute value constraint over x and y corresponding to the expressed distance constraint: $|x - y|$

### Example

The following example shows how to use the distance constraint

```
model "Distance constraints"
 uses "kalis"

 setparam("DEFAULT_LB", -50); setparam("DEFAULT_UB", 50)

 declarations
  x, y, z: cpvar
  Dist: cpctr
 end-declarations

 setname(x,"x")
 setname(y,"y")
 setname(z,"z")

 abs(x) = y
 writeln("Absolute value of x: ", x,y,z)

 y >= 20
 writeln("Bounding y by 20: ", x,y,z)

! abs(y-z) <= 3
! Equivalent version of this constraint:
 distance(y,z) <= 3

 writeln("Max distance betw. y and z: ", x,y,z)

 Dist:= distance(x,z) = 5

 if(cp_post(Dist)) then
  writeln("Distance between x and z: ", x,y,z)
 else
  writeln("Problem is infeasible")
 end-if

 cp_show_prob

end-model
```

### Related topics

abs

# abs

### Purpose

This constraint states that a variable y equals the absolute value of another variable x

### Synopsis

```
abs(x) = y with x,y:cpvar
abs(x) = I with x:cpvar and I:integer
x = abs(y) with x,y:cpvar
I = abs(x) with I:integer and x:cpvar
abs(x) <= I with x:cpvar and I:integer
I <= abs(x) with I:integer and x:cpvar
abs(x) >= I with x:cpvar and I:integer
I >= abs(x) with I:integer and x:cpvar
abs(x) <>I with x:cpvar and I:integer
I <>abs(x) with I:integer and x:cpvar
```

### Arguments

| | |
|---|---|
| `x` | absolute value variable (of type `cpvar`, `cpfloatvar`, `cplinexp`, `cpnlinexp`) |
| `y` | value variable (of the same type as `x`) |
| `I` | integer value |

### Return value

An absolute value constraint over the arguments

### Example

The following example shows how to use the absolute value constraint

```
model "Distance constraints"
 uses "kalis"

 setparam("DEFAULT_LB", -50); setparam("DEFAULT_UB", 50)

 declarations
  x, y, z: cpvar
  Dist: cpctr
 end-declarations

 setname(x,"x")
 setname(y,"y")
 setname(z,"z")

 abs(x) = y
 writeln("Absolute value of x: ", x,y,z)

 y >= 20
 writeln("Bounding y by 20: ", x,y,z)

! abs(y-z) <= 3
! Equivalent version of this constraint:
 distance(y,z) <= 3

 writeln("Max distance betw. y and z: ", x,y,z)

 Dist:= distance(x,z) = 5
```

```
 if(cp_post(Dist)) then
  writeln("Distance between x and z: ", x,y,z)
 else
  writeln("Problem is infeasible")
 end-if

 cp_show_prob

end-model
```

### Related topics

distance

# all_different

### Purpose

The all_different constraint states that all variables in this constraint must be pairwise different:

### Synopsis

```
function all_different(vars:set of cpvar, propagation:  integer) :  cpctr
function all_different(vars:set of cpvar) :  cpctr
function all_different(vars:array(range) of cpvar, propagation:integer) :
      cpctr
function all_different(vars:array(range) of cpvar) :  cpctr
function all_different(vars:cpvarlist, propagation:integer) :  cpctr
function all_different(vars:cpvarlist) :  cpctr
```

### Arguments

`vars` the list of variables

`propagation` Propagation type selected using a constant `KALIS_FORWARD_CHECKING`,`KALIS_GEN_ARC_CONSISTENCY`

### Return value

An all different constraint over vars

### Example

Consider the following simple problem where one must determine the arrival positions of a set of six runners: Dominique, Ignace, Naren, Olivier, Philippe and Pascal.
The constraints are the following:

1. All runners have different positions
2. Olivier is not last
3. Dominique, Pascal, and Ignace are before Naren and Olivier
4. Dominique is better than third
5. Philippe is among the first four
6. Ignace is neither second nor third
7. Pascal is three places higher than Naren
8. Neither Ignace nor Dominique are in fourth position

This problem can be modeled as follows. We create one variable per runner, whose value will be his arrival position. The initial domains of the variables will be the available arrival positions (1-6). Since we admit there are no ties, the positions are all pairwise different.

```
model "all_different example"
 uses "kalis"

 declarations
  PEOPLE = {"Sebastian", "Frederic", "Jan-Georg",
            "Krzysztof","Maarten","Luca"}  ! Set of speakers
  x: array(PEOPLE) of cpvar                ! Time slot per person
 end-declarations

 3 <= x("Sebastian") ; x("Sebastian") <= 6
 3 <= x("Frederic")  ;  x("Frederic") <= 4
 2 <= x("Jan-Georg") ; x("Jan-Georg") <= 5
 2 <= x("Krzysztof") ; x("Krzysztof") <= 4
 3 <= x("Maarten")   ;   x("Maarten") <= 4
 1 <= x("Luca")      ;      x("Luca") <= 6
```

```
! A different time slot for every person
 all_different(x)

! Solve the problem
 if not(cp_find_next_sol) then
  writeln("Problem is infeasible")
  exit(1)
 end-if

! Solution printout
 writeln(x)

end-model
```

### Related topics

distribute KALIS_GEN_ARC_CONSISTENCY KALIS_FORWARD_CHECKING

# cycle

## Purpose

The cycle constraint ensures that the graph implicitly represented by a set of variables (= nodes) and their domains (= possible successors of a node) contains no sub-tours, that is, tours visiting only a subset of the nodes. The constraint can take an optional second set of variables Preds, representing the inverse relation of the Succ function and ensure the following equivalences: $succ_i = j \Leftrightarrow pred_j = i$ for all i and j. Another optional parameter of the cycle constraint allows to take into account an accumulated quantity along the tour such as distance, time or weight. More formally, it ensures the following constraint: $quantity = \sum_{i,j} distmatrix_{ij}$ for all arcs $i \rightarrow j$ belonging to the tour.

## Synopsis

```
function cycle(succ:array of cpvar) :  cpctr
function cycle(succ:array of cpvar, pred:array of cpvar) :  cpctr
function cycle(succ:array of cpvar, dist:cpvar, distmatrix:array(range,range)
      of integer) :  cpctr
function cycle(succ:array of cpvar, pred:array of cpvar, dist:cpvar,
      distmatrix:array(range,range) of integer) :  cpctr
```

## Arguments

`succ` the list of successors variables

`pred` the list of predecessors variables

`dist` the accumulated quantity variable

`distmatrix` a (nodes $\times$ nodes) matrix of integers representing the quantity to add to the accumulated quantity variable when an edge (i,j) belongs to the tour.

## Return value

A cycle constraint

## Example

To illustrate the cycle constraint we show an implementation of the Traveling Salesman Problem (TSP). The objective of the Traveling Salesman Problem (TSP) is to find the shortest tour through a given set of cities that visits each city exactly once (a Hamiltonian tour). More formally, given a set of n points and a distance between every pair of points, a solution to the TSP is a path of N edges, with identical first and last vertices, containing all n points and with minimal total length. This problem can be modeled as follows: a solution is represented by a function Succ associating with each node its immediate successor. We use an array of N variables 'succ(i)' (one for each city $i \in \{0, \ldots, N-1\}$) to represent the next city visited after city number i where the domain of the variables succ(i) is set to $\{0, \ldots, N-1\} - \{i\}$.

```
model "TSP"
 uses "kalis"

 parameters
  S = 14   ! Number of cities to visit
 end-parameters

 declarations
  TC : array(0..3*S) of integer
 end-declarations

 ! TSP DATA
 TC :: [
  1 , 1647,  9610,
  2 , 1647,  9444,
```

```
 3 , 2009,  9254,
 4 , 2239,  9337,
 5 , 2523,  9724,
 6 , 2200,  9605,
 7 , 2047,  9702,
 8 , 1720,  9629,
 9 , 1630,  9738,
 10, 1405,  9812,
 11, 1653,  9738,
 12, 2152,  9559,
 13, 1941,  9713,
 14, 2009,  9455]

forward procedure print_solution

setparam("DEFAULT_LB", 0)
setparam("DEFAULT_UB", S-1)

declarations
 CITIES = 0..S-1                  ! Set of cities
 succ: array(CITIES) of cpvar     ! Array of successor variables
 prev: array(CITIES) of cpvar     ! Array of predecessor variables
end-declarations

setparam("DEFAULT_UB", 10000)

declarations
 dist_matrix: array(CITIES,CITIES) of integer  ! Distance matrix
 totaldist: cpvar                 ! Total distance of the tour
 succpred: cpvarlist              ! Variable list for branching
end-declarations

! Setting the variable names
forall(p in CITIES) do
 setname(succ(p),"succ("+p+")")
 setname(prev(p),"prev("+p+")")
end-do

! Add succesors and predecessors to succpred list for branching
forall(p in CITIES) succpred += succ(p)
forall(p in CITIES) succpred += prev(p)

! Build the distance matrix
forall(p1,p2 in CITIES | p1<>p2)
  dist_matrix(p1,p2) :=  round(sqrt((TC(3*p2+1) - TC(3*p1+1)) *
   (TC(3*p2+1) - TC(3*p1+1)) + (TC(3*p2+2) - TC(3*p1+2)) *
   (TC(3*p2+2) - TC(3*p1+2))))

! Set the name of the distance variable
setname(totaldist, "total_distance")

! Posting the cycle constraint
cycle(succ, prev, totaldist, dist_matrix)

! Print all solutions found
```

```
 cp_set_solution_callback("print_solution")

 ! Set the branching strategy
 cp_set_branching(assign_and_forbid("bestregret", "bestneighbor",
                  succpred))
 setparam("MAX_COMPUTATION_TIME", 5)

 ! Find the optimal tour
 if (cp_minimize(totaldist)) then
  if getparam("SEARCH_LIMIT")=KALIS_SLIM_BY_TIME then
   writeln("Search time limit reached")
  else
   writeln("Done!")
  end-if
 end-if


!---------------------------------------------------------------
! **** Solution printing ****
 procedure print_solution
  writeln("TOUR LENGTH = ", getsol(totaldist))

  thispos:=getsol(succ(0))
  nextpos:=getsol(succ(thispos))
  write("  Tour: ", thispos)
  while (nextpos <> getsol(succ(0))) do
    write(" -> ", nextpos)
    thispos:=nextpos
    nextpos:=getsol(succ(thispos))
  end-do
  writeln
 end-procedure

!---------------------------------------------------------------
! **** Variable choice ****
 function bestregret(Vars: cpvarlist): integer

 ! Get the number of elements of "Vars"
  listsize:= getsize(Vars)
  minindex := 0
  mindist := 0

 ! Set on uninstantiated variables
  forall(i in 1..listsize) do
    if not is_fixed(getvar(Vars,i)) then
      if (i <= S) then
        bestn := getlb(getvar(Vars,i))
        v:=bestn
        mval:=dist_matrix(i-1,v)
        while (v < getub(getvar(Vars,i))) do
          v:=getnext(getvar(Vars,i),v)
          if dist_matrix(i-1,v)<=mval then
            mval:=dist_matrix(i-1,v)
            bestn:=v
          end-if
```

```
        end-do
        sbestn := getlb(getvar(Vars,i))
        mval2:= 10000000
        v:=sbestn
        if (dist_matrix(i-1,v)<=mval2 and v <> bestn) then
          mval2:=dist_matrix(i-1,v)
          sbestn:=v
        end-if
        while (v < getub(getvar(Vars,i))) do
          v:=getnext(getvar(Vars,i),v)
          if (dist_matrix(i-1,v)<=mval2 and v <> bestn) then
            mval2:=dist_matrix(i-1,v)
            sbestn:=v
          end-if
        end-do

      else

        bestn := getlb(getvar(Vars,i))
        v:=bestn
        mval:=dist_matrix(v,i-S-1)
        while (v < getub(getvar(Vars,i))) do
          v:=getnext(getvar(Vars,i),v)
          if dist_matrix(v,i-S-1)<=mval then
            mval:=dist_matrix(v,i-S-1)
            bestn:=v
          end-if
        end-do
        sbestn := getlb(getvar(Vars,i))
        mval2:= 10000000
        v:=sbestn
        if (dist_matrix(v,i-S-1)<=mval2 and v <> bestn) then
          mval2:=dist_matrix(v,i-S-1)
          sbestn:=v
        end-if
        while (v < getub(getvar(Vars,i))) do
          v:=getnext(getvar(Vars,i),v)
          if (dist_matrix(v,i-S-1)<=mval2 and v <> bestn) then
            mval2:=dist_matrix(v,i-S-1)
            sbestn:=v
          end-if
        end-do
      end-if

      dsize := getsize(getvar(Vars,i))

      rank :=  integer(10000/ dsize +(mval2 - mval))
      if (mindist<= rank) then
        mindist := rank
        minindex := i
      end-if

    end-if
  end-do
```

```
  returned := minindex

 end-function

!-----------------------------------------------------------------
! **** Value choice: choose value resulting in smallest distance
 function bestneighbor(x: cpvar): integer

  issucc := false
  idx := -1
  forall (i in CITIES)
    if (is_same(succ(i),x)) then
      idx:= i
      issucc := true
    end-if
  forall (i in CITIES)
    if (is_same(prev(i),x)) then
      idx:= i
    end-if

  if issucc then
    returned:= getlb(x)
    v:=getlb(x)
    mval:=dist_matrix(idx,v)
    while (v < getub(x)) do
      v:=getnext(x,v)
      if dist_matrix(idx,v)<=mval then
        mval:=dist_matrix(idx,v)
        returned:=v
      end-if
    end-do
  else
    returned:= getlb(x)
    v:=getlb(x)
    mval:=dist_matrix(v,idx)
    while (v < getub(x)) do
      v:=getnext(x,v)
      if dist_matrix(v,idx)<=mval then
        mval:=dist_matrix(v,idx)
        returned:=v
      end-if
     end-do
  end-if

 end-function

end-model
```

### Related topics

distribute all_different

## maximum_minimum

**Purpose**

The maximum (resp) minimum constraint states that a variable z is the maximum (resp) minimum of a list of variables vars

**Synopsis**

```
minimum(vars) = z or maximum(vars) = z
z = minimum(vars) or z = maximum(vars)
```

**Arguments**

| | |
|---|---|
| `vars` | list of decision variables: {set of cpvar \| array(range) of cpvar \| cpvarlist} |
| `z` | decision variable for the maximum/minimum: cpvar |

**Return value**

A maximum/minimum constraint over z and vars

**Example**

The following example shows how to use the maximum/minimum constraints:

```
model "Min and Max"
 uses "kalis"

 declarations
  R = 1..5
  x: array(R) of cpvar
  v, w, y: cpvar
  L: cpvarlist
  MaxCtr: cpctr
 end-declarations

 setname(v,"v")
 setname(w,"w")
 setname(y,"y")

 forall(i in R) do
  setname(x(i),"x"+i+"")
  setdomain(x(i), 0, 2*i + round(5*random + 0.5))
 end-do

 writeln("Initial domains:\n ", x, "  ", v)

! Minimum constraint with automated posting
 v = minimum(x)
 writeln("With minimum constraint:\n ", x, "  ", v)

 x(1) = 2
 writeln("Fixing x(1) to 2: ", v)

! Maximum constraint with explicit posting
 MaxCtr:= w = maximum({x(2), x(3), x(5)})
 if cp_post(MaxCtr) then
  writeln("With maximum constraint:\n ", x, "  ", w)
 else exit(1)
 end-if
```

```
 w <= 7
 writeln("Bounding w by 7:\n ", x, "  ", w)

! Maximum constraint on list of variables
 L += x(2); L += x(3); L += x(4)
 y = maximum(L)
 writeln("With 2nd maximum constraint:\n ", x, "  ", y)

 if (cp_find_next_sol) then
  writeln("A solution:\n ", x, "  ", v, "  ", w, "  ", y)
 end-if
end-model
```

## occurrence

**Purpose**

Constrains the number of occurrences of a specific value among a list of decision variables

**Synopsis**

```
occurrence(value,vars) = target with target:integer, value:integer
target = occurrence(value,vars) with target:integer, value:integer
occurrence(value,vars) = occvar with occvar:cpctr, value:integer
occvar = occurrence(value,vars) with occvar:cpctr, value:integer
occurrence(value,vars) <= target with target:integer, value:integer
target <= occurrence(value,vars) with target:integer, value:integer
occurrence(value,vars) <=occvar with occvar:cpctr, value:integer
occvar >= occurrence(value,vars) with occvar:cpctr, value:integer
occurrence(value,vars) >= target with target:integer, value:integer
target >= occurrence(value,vars) with target:integer, value:integer
occurrence(value,vars) >= occvar with occvar:cpctr, value:integer
occvar >= occurrence(value,vars) with occvar:cpctr, value:integer
```

**Arguments**

`target` the target occurrence count for the specified value

`value` the integer value whose occurences in the variable list should be constrained

`vars` the list of decision variables: {set of cpvar | array of cpvar | cpvarlist}

**Return value**

An occurrence constraint over the given arguments

**Example**

The following example shows how to use the occurence constraint:

```
model "Cardinality"
 uses "kalis"

 setparam("DEFAULT_LB", 0)

 declarations
  R = 1..6
  S = 1..10
  x: array(R) of cpvar
  y: array(S) of cpvar
  a,b,c: cpvar
  Card: cpctr
  Vlist: cpvarlist
 end-declarations

 forall(i in R) setname(x(i), "x"+i)
 forall(i in 1..3) x(i) = 1
 forall(i in 4..6) x(i) <= 10
 setname(c, "c")
 c <= 15

 writeln("Initial domains:\n ", x, "  ", c)

! Explicit posting of an occurrence constraint
 Card:= occurrence(1, x) = c
 if cp_post(Card) then
```

```
  writeln("With occurrence constraint:\n ", x, "  ", c)
 else exit(1)
 end-if

 c = 6
 writeln("Fixing occurrence to 6:\n ", x, "  ", c)

 forall(i in S) do
  setname(y(i), "y"+i)
  i <= y(i); y(i) <= i*2
 end-do
 setname(a, "a"); setname(b,"b")

 writeln("Initial domains:\n ", y, "  ", a, "  ", b)

! Occurrence constraint on an array of variables
 occurrence(4, y) <= 2

! Occurrence constraint on a list of variables
 Vlist += y(1); Vlist += y(2); Vlist += y(4)
 occurrence(2, Vlist) = 0

! Occurrence constraint on a set of variables
 occurrence(9, {y(6), y(7), y(9)}) >= 3

! Occurrences bounded by variables
 occurrence(5, y) >= a
 occurrence(8, {y(4), y(5), y(6), y(7), y(8)}) <= b
 writeln("With all constraints:\n ", y, "  ", a, "  ", b)

 if cp_find_next_sol then
  writeln("A solution:\n ", y, "  ", a, "  ", b)
 end-if

end-model
```

**Related topics**

distribute

## element

**Purpose**

This constraint states that a variable z is the $y^{th}$ element of an ordered list of integer V, in its ternary form it states that z is the [x,y]-th element of a matrix of integers M

**Synopsis**

```
element(x+I) = C
element(V,x{,I}) = C
element(V,x{,I}) = y with x,y cpvar and I integer
y = element(V,x{,I}) with x,y cpvar and I integer
element(V,x{,I}) = z with x,y,z cpvar
z = element(M,x,y) with x,y,z cpvar
```

**Arguments**

| | |
|---|---|
| `z` | the value variable |
| `x` | first index variable |
| `y` | second index variable |
| `I` | optional constant offset for index |
| `V` | the list of integer |
| `M` | the matrix of integers |

**Return value**

An element constraint over z, x and y in the ternary form, over x and z in the binary form

**Example**

The following example shows how to use the element constraint:

```
model "Element"
 uses "kalis"

 declarations
  RY = 43..52
  RX = 1..2
  D: array(RY) of integer
  D2: array(RX,RY) of integer
  x,y,d_of_y,d_of_x_y: cpvar
 end-declarations

 D :: (43..52)[ 0,  1,  2,  3,  4,  5,  6,  7,  8,  9]

 D2:: (1..2,43..52)[10, 11, 12, 13, 14, 15, 16, 17, 18, 19,
                    20, 21, 22, 23, 24, 25, 26, 27, 28, 29]

 setname(x, "x")
 setname(y, "y")
 setname(d_of_y, "d_of_y")
 setname(d_of_x_y, "d_of_x_y")

 writeln("Original domains: ", x, y, d_of_y, d_of_x_y)

 element(D,y) = d_of_y
 element(D2,x,y) = d_of_x_y

 writeln("After propagation: ", x, y, d_of_y, d_of_x_y)
```

```
! Solve the problem
 while (cp_find_next_sol) do
  nbSolutions += 1
  writeln("Solution ", nbSolutions, ": x:", getsol(x),
  " y:", getsol(y), " d_of_y:", getsol(d_of_y),
  " d_of_x_y:", getsol(d_of_x_y))
 end-do
 writeln("done!")

end-model
```

## generic_binary_constraint

**Purpose**

This constraint can be used to propagate a user-defined constraint over two variables (its propagation is based on the AC2001 algorithm (cf. [BR01]).

**Synopsis**

```
function generic_binary_constraint(v1:cpvar,v2:cpvar, fctname:string) :
      cpctr
```

**Arguments**

`v1` the first decision variable

`v2` the second decision variable

`fctname` name of the function specifying the user-defined constraint, such a function necessarily takes two cpvar as arguments and returns a Boolean.

**Return value**

A binary constraint over 'v1' and 'v2'

**Example**

The following example shows how to use the generic_binary_constraint constraint to solve the classical Euler Knight Tour problem:

```
model "Euler Knight Moves"
 uses "kalis"

 parameters
  S = 8                                  ! No. of rows/columns
 end-parameters

 N:= S * S                               ! Total number of cells
 setparam("DEFAULT_LB", 0)
 setparam("DEFAULT_UB", N-1)

 declarations
  PATH = 1..N                            ! Cells on the board
  pos: array(PATH) of cpvar              ! Position p in tour
 end-declarations

! Setting names of decision variables
 forall(i in PATH) setname(pos(i), "Position"+i)

! Fix the start position
 pos(1) = 0

! Each cell is visited once
 all_different(pos, KALIS_GEN_ARC_CONSISTENCY)

! The knight's path obeys the chess rules for valid knight moves
 forall(i in 1..N-1)
  generic_binary_constraint(pos(i), pos(i+1), "valid_knight_move")
 generic_binary_constraint(pos(N), pos(1), "valid_knight_move")

! Setting enumeration parameters
 cp_set_branching(probe_assign_var(KALIS_SMALLEST_MIN,
                   KALIS_MAX_TO_MIN, pos, 14))
```

```
! Search for up to NBSOL solutions
 solct:= 0
 if not cp_find_next_sol then
  writeln("No solution")
 else
  writeln(pos)
 end-if

! **** Test whether the move from a to b is admissible ****
 function valid_knight_move(a:integer, b:integer): boolean
  declarations
   xa,ya,xb,yb,delta_x,delta_y: integer
  end-declarations
  xa := a div S
  ya := a mod S
  xb := b div S
  yb := b mod S
  delta_x := abs(xa-xb)
  delta_y := abs(ya-yb)
  returned := (delta_x<=2) and (delta_y<=2) and (delta_x+delta_y=3)
 end-function

end-model
```

## distribute

### Purpose

A distribute constraint also known as GCC (Global Cardinality Constraint) over a set of variables is defined by three arrays called values, lowerBound, and upperBound. The constraint is satisfied if, and only if, the number of variables of the given set, which are assigned to values[i], is greater than or equal to lowerBound[i], and less than or equal to upperBound[i] for all i, and if no variable of the given set is assigned to a value which does not belong to values. The constraint is equivalent, from a modelization point of view, to posting two instances of `occurrence` constraints for each value. But this is absolutely not equivalent from a propagation point of view: distribute acquires a far better propagation, using the Regin algorithm.

### Synopsis

```
function distribute(vars:array of cpvar,values:set of string,
      lowerBound:array(range) of integer, upperBound:array(range) of
      integer) :  cpctr
function distribute(vars:array of cpvar,values:set of string,
      lowerBound:array(range) of integer, upperBound:array(range) of
      integer) :  cpctr
```

### Arguments

`vars` Array of variables

`values` Set of values represented by their names

`lowerBound` Array of lower bounds

`upperBound` Array of upper bounds

### Return value

A distribute constraint

### Example

A simple planning problem for personnel in a theater. Suppose that a movie theatre director has to decide in which location each of his employees should be posted. There are eight employees: Andrew, David, Jane, Jason, Leslie, Michael, Marilyn and Oliver. There are four locations: the ticket office, the first entrance, the second entrance and the coat check. These locations require three, two, two, and one person respectively. This constraint will be modeled by one distribute constraint:

```
model "Distribute example"
 uses "kalis"

 declarations
  PERS = {"David","Andrew","Leslie","Jason","Oliver","Michael",
          "Jane","Marilyn"}           ! Set of personnel
  LOC = 1..4                          ! Set of locations
  REQ: array(LOC) of integer          ! No. of pers. req. per loc.
  place: array(PERS) of cpvar         ! Workplace for each peson
 end-declarations

! Initialize data
 REQ:: [3, 2, 2, 1]

! Each variable has a lower bound of 1 (Ticket office) and
!  an upper bound of 4 (Cloakroom)
 forall(p in PERS) do
  setname(place(p), "workplace("+p+")")
  1 <= place(p); place(p) <= 4
```

```
 end-do

! Creation of a resource constraint of for every location
 forall(d in LOC) occurrence(d, place) = REQ(d)

! Elegant way to declare theses constraints,
! moreover achieving stronger prunning (using global
! cardinality constraint)
 distribute(place, LOC, REQ)

! Solve the problem
 if not(cp_find_next_sol) then
  writeln("Problem is infeasible")
  exit(1)
 end-if

! Solution printout
 writeln(place)

end-model
```

## Related topics

occurrence all_different

# cumulative

## Purpose

This constraint states that the tasks requiring a resource do not exceed the resource capacity. The primary use of this constraint is to express resource constraints.

## Synopsis

```
function cumulative(starts: array(integer) of cpvar, durations:array(integer)
      of cpvar, ends: array(integer) of cpvar, usages: array(integer) of
      cpvar, sizes: array(integer) of cpvar, C: integer) : cpctr
function cumulative(starts: array(integer) of cpvar, durations:array(integer)
      of cpvar, ends: array(integer) of cpvar, usages: array(integer) of
      cpvar, sizes: array(integer) of cpvar, C: array(integer) of integer)
      : cpctr
```

## Arguments

`starts` Array of variables representing the start times of the tasks

`ends` Array of variables representing the completion times of the tasks

`durations` Array of variables representing the durations of the tasks

`usages` Array of variables representing the resource consumptions of the tasks

`sizes` Array of variables representing the sizes of the tasks

`C` integer representing the initial capacity of the resource (constant over time or capacity value for each time period)

## Return value

A cumulative constraint ensuring that the maximal resource capacity is never exceded. More formally the constraint ensures that

$starts_j + durations_j = ends_j$ for all j in Tasks

$usages_j \cdot durations_j = sizes_j$ for all j in Tasks

$\sum_{j \in Tasks | t \in [UB(start_j)..LB(end_j)]} usages_j \leq C_t$ for all times t in the planning period

## Example

The following example shows how to use the cumulative constraint to express resource constraints for five tasks using the same resource:

```
model "Cumulative scheduling"
 uses "kalis"

 declarations
  TASKS = 1..5
  obj : cpvar
  starts, ends, durations, usages, sizes : array(TASKS) of cpvar
 end-declarations

 C := 2                       ! Resource capacity
 HORIZON := 10                ! Time horizon

! Setting up the variables representing task properties
 forall (t in TASKS) do
  starts(t).name:= "T"+t+".start"
  ends(t).name:= "T"+t+".end"
  durations(t).name:= "T"+t+".duration"
  sizes(t).name:= "T"+t+".size"
```

```
  usages(t).name:= "T"+t+".use"
  0 <= starts(t); starts(t) <= HORIZON
  0 <= ends(t); ends(t) <= HORIZON
  t <= durations(t); durations(t) <= t+1
  1 <= sizes(t); sizes(t) <= 100
  1 <= usages(t); usages(t) <= 1
  obj >= ends(t)
 end-do

! Cumulative resource constraint
 cumulative(starts, durations, ends, usages, sizes, C)

! Define the branching strategy
 cp_set_branching(assign_var(KALIS_SMALLEST_MIN,KALIS_MIN_TO_MAX))

! Solve the problem
 if cp_minimize(obj) then
  cp_show_sol
  write("Resource use profile: ")
  forall(t in TASKS, time in 0..HORIZON)
   if (starts(t).sol <= time) and (ends(t).sol > time) then
    rload(time) += usages(t).sol
   end-if
  forall(time in 0..HORIZON) write(rload(time))
  writeln
 else
  writeln("No solution found")
 end-if

end-model
```

### Related topics

disjunctive settle_disjunction or

# disjunctive

### Purpose

This constraint states that the given tasks are not overlapping chronologically.

### Synopsis

```
procedure disjunctive(starts:  set of cpvar, durations:array(cpvar) of
      integer, disj:set of cpctr, resource:integer)
procedure disjunctive(starts:  array(integer) of cpvar,
      durations:array(integer) of cpvar, ends:  array(integer) of cpvar)
```

### Arguments

`starts` Array of variables representing the start times of the tasks

`durations` Array of integers representing the durations of the tasks

`ends` Array of variables representing the completion times of the tasks

`disj` Empty array that will be filled with the list of disjunctions that will be created by this constraint

`resource` Resource flag (argument currently unused)

### Return value

A disjunctive constraint ensuring that the tasks defined by 'starts' and 'durations' are not overlapping chronologically.

### Example

The following example shows how to use the disjunctive constraint to express resource constraints in a small disjunctive scheduling problem:

```
model "Disjunctive scheduling with settle_disjunction"
 uses "kalis"

 declarations
  NBTASKS = 5
  TASKS = 1..NBTASKS                        ! Set of tasks
  DUR: array(TASKS) of integer              ! Task durations
  DURs: array(set of cpvar) of integer      ! Durations
  DUE: array(TASKS) of integer              ! Due dates
  WEIGHT: array(TASKS) of integer           ! Weights of tasks
  start: array(TASKS) of cpvar              ! Start times
  tmp: array(TASKS) of cpvar                ! Aux. variable
  tardiness: array(TASKS) of cpvar          ! Tardiness
  twt: cpvar                                ! Objective variable
  zeroVar: cpvar                            ! 0-valued variable
  Strategy: array(range) of cpbranching     ! Branching strategy
  Disj: set of cpctr                        ! Disjunctions
 end-declarations

 DUR :: [21,53,95,55,34]
 DUE :: [66,101,232,125,150]
 WEIGHT :: [1,1,1,1,1]

 setname(twt, "Total weighted tardiness")
 zeroVar = 0
 setname(zeroVar, "zeroVar")

! Setting up the decision variables
 forall (t in TASKS) do
```

```
  start(t) >= 0
  setname(start(t), "Start("+t+")")
  DURs(start(t)):= DUR(t)
  tmp(t) = start(t) + DUR(t) - DUE(t)
  setname(tardiness(t), "Tard("+t+")")
  tardiness(t) = maximum({tmp(t), zeroVar})
 end-do

 twt = sum(t in TASKS) (WEIGHT(t) * tardiness(t))

! Create the disjunctive constraints
 disjunctive(union(t in TASKS) {start(t)}, DURs, Disj, 1)

! Define the search strategy
 Strategy(1):= settle_disjunction
 Strategy(2):= split_domain(KALIS_LARGEST_MIN,KALIS_MIN_TO_MAX)
 cp_set_branching(Strategy)
 setparam("DICHOTOMIC_OBJ_SEARCH",true)

 if not(cp_minimize(twt)) then
  writeln("Problem is inconsistent")
  exit(0)
 end-if

 forall (t in TASKS)
  writeln("[", getsol(start(t)), "==>",
          getsol(start(t)) + DUR(t), "]:\t ",
  getsol(tardiness(t)), "  (", getsol(tmp(t)), ")")
 writeln("Total weighted tardiness: ", getsol(twt))

end-model
```

### Related topics

or settle_disjunction

## producer_consumer

### Purpose

A Producer Consumer Scheduling constraint. More formally the constraint ensures that:

$productions_j \cdot durations_j = prodsizes_j$ for all j in Tasks

$consumptions_j \cdot durations_j = consosizes_j$ for all j in Tasks

$\sum_{j \in R | t \in [UB(start_j)..LB(end_j)]} (productions_j - consumptions_j) \leq C_t$ for all t in Times

### Synopsis

```
function producer_consumer(starts:array(range) of cpvar, ends:array(range)
      of cpvar, durations:array(range) of cpvar, productions:array(range)
      of cpvar, prod_sizes:array(range) of cpvar, consumptions:array(range)
      of cpvar, conso_sizes:array(range) of cpvar, C:array(range) of
      integer) : cpctr
```

### Arguments

`starts` array of starting times

`ends` array of ending times

`durations` array of durations

`productions` array of tasks' requirements

`prod_sizes` array of tasks' productions

`consumptions` array of tasks' provisions

`conso_sizes` array of tasks' consumptions

`C` initial resource capacity array indexed by time

### Example

The following example shows how to use the producer_consumer constraint for the problem of planning the construction of a house (an example of resource-constrained project scheduling).

```
model "Cumulative Scheduling"
 uses "kalis"

 setparam("DEFAULT_LB",0)
 setparam("DEFAULT_UB",100)

 declarations
 ! Task indices
  Masonry = 1; Carpentry= 2; Roofing       = 3; Windows      = 4
  Facade   = 5; Garden    = 6; Plumbing      = 7; Ceiling      = 8
  Painting= 9; MovingIn =10; InitialPayment=11; SecondPayment=12
  BUILDTASKS = 1..10
  PAYMENTS = 11..12
  TASKS = BUILDTASKS+PAYMENTS
  TNAMES: array(TASKS) of string

  obj:cpvar                                ! Objective variable
  starts   : array(TASKS) of cpvar         ! Start times variables
  ends     : array(TASKS) of cpvar         ! Completion times
  durations: array(TASKS) of cpvar         ! Durations of tasks
  consos   : dynamic array(TASKS) of cpvar ! Res. consumptions
  sizes    : dynamic array(TASKS) of cpvar ! Consumption sizes
  prods    : dynamic array(TASKS) of cpvar ! Res. production
  sizep    : dynamic array(TASKS) of cpvar ! Production sizes
```

```
 Strategy : cpbranching                   ! Branching strategy
end-declarations

TNAMES:: (1..12)["Masonry", "Carpentry", "Roofing", "Windows",
          "Facade", "Garden", "Plumbing", "Ceiling", "Painting",
  "MovingIn", "InitialPayment", "SecondPayment"]

! Setting the names of the variables
 forall(j in TASKS) do
   starts(j).name := TNAMES(j)+".start"
   ends(j).name := TNAMES(j)+".end"
   durations(j).name := TNAMES(j)+".duration"
 end-do

! Creating consumption variables
 forall(j in BUILDTASKS) do
   create(sizes(j))
   sizes(j).name := TNAMES(j)+".size"
   create(consos(j))
   consos(j).name := TNAMES(j)+".conso"
 end-do

! Setting durations of building tasks
durations(Masonry) =7; durations(Carpentry)=3; durations(Roofing) =1
durations(Windows) =1; durations(Facade)   =2; durations(Garden)  =1
durations(Plumbing)=8; durations(Ceiling)  =3; durations(Painting)=2
durations(MovingIn)=1

! Precedence constraints among building tasks
starts(Carpentry) >= ends(Masonry)
starts(Roofing)   >= ends(Carpentry)
starts(Windows)   >= ends(Roofing)
starts(Facade)    >= ends(Roofing)
starts(Garden)    >= ends(Roofing)
starts(Plumbing)  >= ends(Masonry)
starts(Ceiling)   >= ends(Masonry)
starts(Painting)  >= ends(Ceiling)
starts(MovingIn)  >= ends(Windows)
starts(MovingIn)  >= ends(Facade)
starts(MovingIn)  >= ends(Garden)
starts(MovingIn)  >= ends(Painting)

! Setting task consumptions
consos(Masonry)  = 7; consos(Carpentry) = 3; consos(Roofing)  = 1
consos(Windows)  = 1; consos(Facade)    = 2; consos(Garden)   = 1
consos(Plumbing) = 8; consos(Ceiling)   = 3; consos(Painting) = 2
consos(MovingIn) = 1

! Production (amount) of payment tasks
forall(j in PAYMENTS) do
 create(prods(j))
 prods(j).name := TNAMES(j)+".prod"
 create(sizep(j))
 sizep(j).name := TNAMES(j)+".sizep"
end-do
```

```
! Payment data
 prods(InitialPayment)     = 20; prods(SecondPayment)     = 9
 durations(InitialPayment) = 1; durations(SecondPayment) = 1
 starts(InitialPayment)    = 0; starts(SecondPayment)    = 15


! Objective: makespan of the schedule
 obj = maximum({ ends(Masonry) , ends(Carpentry), ends(Roofing),
         ends(Windows), ends(Facade), ends(Garden), ends(Plumbing),
 ends(Ceiling), ends(Painting), ends(MovingIn)})

! Posting the producer_consumer constraint
 producer_consumer(starts,ends,durations,prods,sizep,consos,sizes)

! Setting the search strategy
 Strategy:= assign_var(KALIS_SMALLEST_MIN, KALIS_MIN_TO_MAX, starts)
 cp_set_branching(Strategy)

! Find the optimal solution
 if cp_minimize(obj) then
  writeln("Minimum makespan: ", obj.sol)
  forall(j in BUILDTASKS)
    writeln(TNAMES(j), ": ", starts(j).sol, " - ", ends(j).sol)
 else
  writeln("No solution found")
 end-if

end-model
```

### Related topics

cumulative

## 9.2 Constraint parameters

## getarity

### Purpose

Returns the number of decision variables involved in the constraint; this function can be used, for instance, to design advanced search heuristics

### Synopsis

```
function getarity(ctr:cpctr) :  integer
```

### Argument

`ctr` the constraint to explore

### Return value

The number of variables involved in ctr

### Example

The following example shows how to get the arity of a constraint

```
getarity(x + y = 3)
```

## getpriority

### Purpose

Returns the priority of a disjunction passed in argument; this feature is intended for advanced use in dynamically prioritizing the disjunction for solving (highest priority constraints are handled first)

### Synopsis

```
function getpriority(ctr:cpctr) :  integer
```

### Argument

`ctr` The constraint to explore (disjunction only)

### Return value

The associated priority

### Example

The following example shows how to get the priority of a constraint

```
getpriority((x + y = 3) or (x + y = 1))
```

### Related topics

`setpriority`

## setpriority

### Purpose

Sets the priority of a constraint passed in argument

### Synopsis

```
procedure setpriority(ctr:cpctr, priority:integer)
```

### Arguments

`ctr` the constraint (disjunction only)

`priority` a user-defined integer (the higher it will be, the quicker the disjunction will be activated)

### Example

The following example shows how to set the priority of a constraint:

```
setpriority((x + y = 3) or (x + y = 1),2)
```

### Related topics

`getpriority`

## gettag

**Purpose**

Gets the tag (user-defined integer information) of a constraint

**Synopsis**

```
function gettag(ctr:cpctr) :  integer
```

**Argument**

| | |
|---|---|
| `ctr` | the constraint |

**Return value**

The tag that has been previously associated to it

**Example**

The following example shows how to get the tag of a constraint ctr

```
writeln(gettag(ctr))
```

**Related topics**

`settag`

# settag

### Purpose

Sets the tag (user-defined integer information) of a constraint

### Synopsis

```
procedure settag(ctr:cpctr,tag:integer)
```

### Arguments

| | |
|---|---|
| `ctr` | the constraint |
| `tag` | the tag |

### Example

The following example shows how to set the tag of a constraint to '32'

```
settag(ctr,32)
```

### Related topics

`gettag`

## setfirstbranch

**Purpose**

This procedure enables the user to specify the first constraint of a disjunction to be activated; thus, it is possible to create dynamical heuristics for disjunctions.

**Synopsis**

```
procedure setfirstbranch(disj:cpctr, firstbranch:integer)
```

**Arguments**

`disj` the involved constraint (only a disjunction)

`firstbranch` 0 to activate the first part and 1 else

**Related topics**

`disjunctive` or `getactivebranch`

## getactivebranch

### Purpose

This function enables the user to know which part of a disjunction is active; if the first constraint of the disjunction is satisfied, it returns zero, else it returns one.

### Synopsis

```
function getactivebranch(disj:cpctr) :  integer
```

### Argument

`disj` the involved constraint (only a disjunction)

### Return value

Zero if the first part of the disjunction is satisfied, one otherwise.

### Example

The following code shows how to retrieve the active branch information from the disjunction disj:

```
b:=getactivebranch(disj)
```

### Related topics

`disjunctive` or `setfirstbranch`

## 9.3 Variables



## getlb

### Purpose

This function returns the current lower bound of the domain of the variable passed in the argument.

### Synopsis

```
function getlb(x:cpvar) :  integer
function getlb(x:cpfloatvar) :  real
```

### Argument

`x`	the decision variable

### Return value

The current lower bound of variable x

### Example

The following example shows how to get the lower bound of a cpvar `x`

```
val:=getlb(x)
```

### Related topics

`default_lb` `getub` `getmiddle` `getsize` `getval` `is_fixed` `getdegree` `gettarget` `getrand` `getnext` `getprev` `contains`

# getub

### Purpose

This function returns the current upper bound of the domain of the variable passed in the argument.

### Synopsis

```
function getub(x:cpvar) :  integer
function getub(x:cpfloatvar) :  real
```

### Argument

`x` the decision variable

### Return value

The current upper bound of x

### Example

The following example shows how to get the upper bound of a cpvar `x`

```
val:=getub(x)
```

### Related topics

default_ub getlb getmiddle getsize getval is_fixed getdegree gettarget getrand getnext getprev contains

## getmiddle

### Purpose

This function returns the value nearest to the middle of the domain of the variable passed in the argument. It can be useful for specific search strategies.

### Synopsis

```
function getmiddle(x:cpvar) :  integer
function getmiddle(x:cpfloatvar) :  real
```

### Argument

`x` the decision variable

### Return value

The middle value of a variable

### Example

The following example shows how to get the middle value of a cpvar `x`'

```
val:=getmiddle(x)
```

### Related topics

getlb getub getsize getval is_fixed getdegree gettarget getrand getnext getprev contains

## getsize

### Purpose

This function returns the cardinality (number of distinct values) of the domain of the variable passed in argument in the case of cpvar and the size of the domain interval representation of the domain in the case of a cpfloatvar.

### Synopsis

```
function getsize(x:cpvar) : integer
function getsize(x:cpfloatvar) : integer
```

### Argument

`x` the decision variable

### Return value

The cardinality / size of the interval representation of the domain of `x`

### Example

The following example shows how to get the size of the domain of a cpvar `x`

```
sz:=getsize(x)
```

### Related topics

`getlb` `getub` `getmiddle` `getval` `is_fixed` `getdegree` `gettarget` `getrand` `getnext` `getprev` `contains`

## getval

### Purpose

This function returns the instantiation value of a variable passed in argument. Note that the variable must be instantiated before calling this function, else it will return its lower bound.

### Synopsis

```
function getval(x:cpvar) :  integer
```

### Argument

`x` the decision variable

### Return value

The instantiation value of x (or by default its lower bound)

### Example

The following example shows how to get the instantiation value of a cpvar X

```
val:=getval(X)
```

### Related topics

getlb getub getmiddle getsize is_fixed getdegree gettarget getrand getnext getprev contains

# is_fixed

### Purpose

Returns `true` if the variable passed in argument has a domain reduced to a singleton.

### Synopsis

```
function is_fixed(var:cpvar) : boolean
function is_fixed(var:cpfloatvar) : boolean
```

### Argument

`var` the decision variable

### Return value

`true` if var has been instantiated

### Example

The following example shows how to see if a cpvar `var` is instantiated

```
if is_fixed(var) then
  write('value of var is ', getval(var))
end-if
```

### Related topics

getlb getub getmiddle getsize getsol getval getdegree gettarget getrand getnext getprev contains

## getdegree

### Purpose

Returns the degree in the constraint graph of the decision variable passed in argument (i.e., the number of constraints that involve it); this can be used for advanced search heuristics.

### Synopsis

```
function getdegree(x:cpvar) :  integer
function getdegree(x:cpfloatvar) :  integer
```

### Argument

`x` the decision variable

### Return value

The degree of x

### Example

The following example shows how to get the degree of a cpvar `x`

```
d:=getdegree(x)
```

### Related topics

getlb getub getmiddle getsize getval is_fixed gettarget getrand getnext getprev contains

## gettarget

### Purpose

Returns the target value (preferred value for instantiation) for the variable passed in argument

### Synopsis

```
function gettarget(var:cpvar) : integer
function gettarget(var:cpfloatvar) : real
```

### Argument

`var` the decision variable

### Return value

The target value of var

### Example

The following example shows how to get the target value of a cpvar 'x'

```
tval := gettarget(x)
```

### Related topics

settarget getlb getub getmiddle getsize getval is_fixed getdegree getrand getnext getprev contains

## getrand

**Purpose**

Returns a value at random (uniform distribution) in the domain of the variable passed in argument.

**Synopsis**

```
function getrand(x:cpvar) :  integer
function getrand(x:cpfloatvar) :  real
```

**Argument**

`x` the decision variable

**Return value**

A random value in the domain of x

**Example**

The following example shows how to get a random value in the domain a cpvar `x`

```
r:=getrand(x)
```

**Related topics**

`getlb` `getub` `getmiddle` `getsize` `getval` `is_fixed` `getdegree` `gettarget` `getnext` `getprev` `contains`

## getnext

### Purpose

Returns the value nearest to and greater than `val` in the domain of a variable passed in argument. This function is useful to enumerate the values of the domain of a variable from the lowest to the highest value; note that if 'val' is larger than the upper bound of the domain of x, the upper bound will be returned.

### Synopsis

```
function getnext(x:cpvar,val:integer) :  integer
```

### Arguments

| | |
|---|---|
| `x` | the decision variable |
| `val` | a value in the domain of the variable |

### Return value

The next value in the domain of x

### Example

The following example shows how to enumerate in increasing order the values in the domain of a cpvar `x`

```
curVal := getlb(x)
while (curVal < getub(x)) do
   curVal := getnext(x, curVal)
   writeln("curVal= ", curVal)
end-do
```

### Related topics

`getlb` `getub` `getmiddle` `getsize` `getval` `is_fixed` `getdegree` `gettarget` `getrand` `getprev` `contains`

## getprev

### Purpose

Returns the value nearest to and lower than 'val' in the domain of a variable passed in argument. This function is useful to enumerate the values of the domain of a variable from the highest to the lowest value; note that if 'val' is below the lower bound of x domain, the lower bound will be returned.

### Synopsis

```
function getprev(x:cpvar,val:integer) :  integer
```

### Arguments

| | |
|---|---|
| `x` | the decision variable |
| `val` | a value in the domain of the variable |

### Return value

The previous value in the domain of x

### Example

The following example shows how to enumerate in decreasing order the values in the domain of a cpvar `x`

```
curVal := getub(x)
while (curVal > getlb(x)) do
   curVal := getprev(x, curVal)
   writeln ("curVal= ",curVal)
end-do
```

### Related topics

`getlb` `getub` `getmiddle` `getsize` `getval` `is_fixed` `getdegree` `gettarget` `getrand` `getnext` `contains`

# contains

### Purpose

Returns `true` if the value 'val' belongs to the domain of the variable passed in argument

### Synopsis

```
function contains(x:cpvar,val:integer) :  boolean
function contains(x:cpfloatvar,val:real) :  boolean
```

### Arguments

| | |
|---|---|
| `x` | the decision variable |
| `val` | the value |

### Return value

`true` if x can be instantiated to `val`

### Example

The following example shows how to test if a value belongs to the domain of a cpvar `x`

```
if contains(x,3) then
  write("x can be instantiated to three!")
end-if
```

### Related topics

getlb getub getmiddle getsize getval is_fixed getdegree gettarget getrand getnext getprev

# is_equal

### Purpose

Returns `true` if the domains of the two variables passed in argument contain exactly the same values

### Synopsis

```
function is_equal(var1:cpvar,var2:cpvar) : boolean
function is_equal(var1:cpfloatvar,var2:cpfloatvar) : boolean
```

### Arguments

| | |
|---|---|
| `var1` | the first decision variable |
| `var2` | the second decision variable |

### Return value

`true` if the domain of `var1` equals the domain of `var2`, else `false`

### Example

The following example shows how to test whether the domains of two cpvar `var1` and `var2` are equal

```
if is_equal(var1,var2) then
  write("the domains of var1 and var2 are the same!")
end-if
```

### Related topics

`is_same`

# is_same

### Purpose

Returns `true` if two decision variables passed in argument represent the same variable; this function is mainly used by advanced users to specify branching heuristics (see example below).

### Synopsis

```
function is_same(var1:cpvar,var2:cpvar) : boolean
function is_same(var1:cpfloatvar,var2:cpfloatvar) : boolean
```

### Arguments

| | |
|---|---|
| `var1` | the first decision variable |
| `var2` | the second decision variable |

### Return value

`true` if `var1` and `var2` represent the same variable

### Example

The following example shows how to test whether two cpvar represent the same variable

```
if is_same(var1,var2) then
  write("var1 and var2 represent the same variable!")
end-if
```

### Related topics

`is_equal`

## settarget

### Purpose

Sets the target value (preferred instantiation value) for the variable passed in argument.

### Synopsis

```
procedure settarget(x:cpvar,value:integer)
procedure settarget(x:cpfloatvar,value:real)
```

### Arguments

| | |
|---|---|
| `x` | the decision variable |
| `value` | the target value |

### Example

The following example shows how to set the target value of a cpvar `x` to three:

```
settarget(x,3)
```

### Related topics

`getlb` `getub` `getmiddle` `getsize` `getval` `is_fixed` `getdegree` `gettarget` `getrand` `getnext` `getprev`

## setdomain

### Purpose

Sets the domain of the variable to the set of integers passed in argument.

### Synopsis

```
procedure setdomain(x:cpvar, domain:set of integers)
procedure setdomain(x:cpvar, lowerBound:integer, upperBound:integer)
procedure setdomain(x:cpfloatvar, lowerBound:real, upperBound:real)
```

### Arguments

| | |
|---|---|
| `x` | the decision variable |
| `domain` | Set of integers representing the target domain. |
| `lowerBound` | lower bound of the interval |
| `upperBound` | upper bound of the interval |

### Example

The following example shows how to set the domain of a cpvar `x` to the set of integers {1,3,5,7,9}

```
setdomain(x,{1,3,5,7,9})
```

### Related topics

getlb getub getmiddle getsize getval is_fixed getdegree gettarget getrand getnext getprev

# setlb

### Purpose

Sets the lower bound of the variable to the value passed in argument. This procedure can be used during the CP search.

### Synopsis

```
procedure setlb(x:cpvar, value:integer)
procedure setlb(x:cpfloatvar, value:real)
```

### Arguments

| | |
|---|---|
| `x` | the decision variable, |
| `value` | value representing the lower bound. |

### Example

The following example shows how to set the lower bound of a cpvar `x` to the integer value `1`.

```
setlb(x,1)
```

### Related topics

`setval` `setub` `instantiate` `getlb` `getub` `getval` `is_fixed`

## setub

### Purpose

Sets the upper bound of the variable to the value passed in argument. This procedure can be used during the CP search.

### Synopsis

```
procedure setub(x:cpvar, value:integer)
procedure setub(x:cpfloatvar, value:real)
```

### Arguments

| | |
|---|---|
| `x` | the decision variable, |
| `value` | value representing the upper bound. |

### Example

The following example shows how to set the upper bound of a cpvar `x` to the integer value `1`.

```
setub(x,1)
```

### Related topics

`setval` `setlb` `instantiate` `getlb` `getub` `getval` `is_fixed`

# setval

## Purpose

Sets the value of the variable to the value passed in argument. This procedure can be used during the CP search.

## Synopsis

```
procedure setval(x:cpvar, value:integer)
procedure setval(x:cpfloatvar, value:real)
```

## Arguments

| | |
|---|---|
| `x` | the decision variable, |
| `value` | instantiation value. |

## Example

The following example shows how to instantiate the value of a cpvar `x` to the integer value `1`.

```
setval(x,1)
```

## Related topics

`instantiate` `setlb` `setub` `getlb` `getub` `getval` `is_fixed`

# instantiate

### Purpose

Sets the value of the variable to the value passed in argument. This procedure can be used during the CP search.

### Synopsis

```
procedure instantiate(x:cpvar, value:integer)
procedure instantiate(x:cpvar, value:real)
```

### Arguments

| | |
|---|---|
| `x` | the decision variable |
| `value` | value. |

### Example

The following example shows how to instantiate the value of a cpvar `x` to the integer value `1`.

```
setval(x,1)
```

### Related topics

`setval` `setlb` `setub` `getlb` `getub` `getval` `is_fixed`

# setprecision

## Purpose

Sets the precision relativity and value of a cpfloatvar

## Synopsis

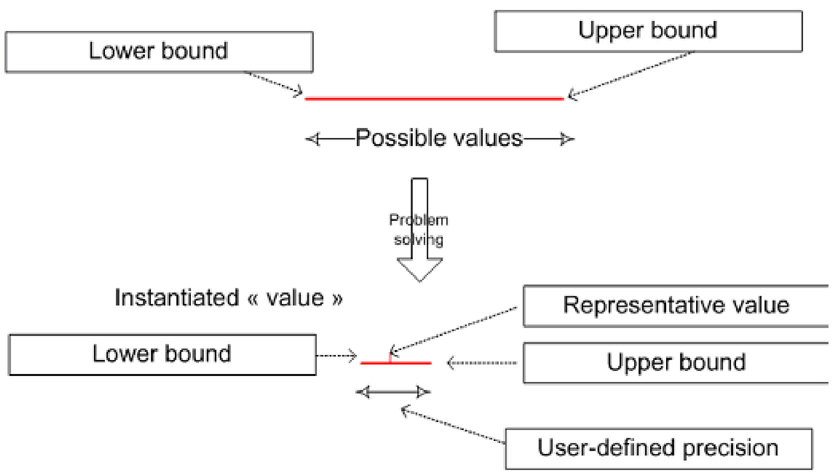
```
procedure setprecision(x:cpfloatvar, relativity:boolean, precision:real)
procedure setprecision(x:cpfloatvar, precision:real)
```

## Arguments

| | |
|---|---|
| `x` | the variable |
| `relativity` | relativity of precision |
| `precision` | precision value |

## Example

The following picture illustrates the concept of precision for a cpfloatvar



## cp_show_var

**Purpose**

This procedure prints the current domain of the variable passed in argument

**Synopsis**

```
procedure cp_show_var(var:cpvar)
procedure cp_show_var(var:cpfloatvar)
```

**Argument**

| | |
|---|---|
| `var` | the decision variable to show |

**Related topics**

`cp_show_prob` `cp_show_stats`

## 9.4 Problem



## cp_post

### Purpose

This function posts the constraint ctr to the problem. Note that posting a constraint does not imply that the involved variables will be instantiated.

### Synopsis

```
function cp_post(ctr:cpctr) : boolean
```

### Argument

`ctr` the constraint to post

### Return value

Returns `true` if the constraint is compatible with already posted constraints, else `false`.

### Example

The following example shows how to post the constraint x = y + 1 where x and y are two decision variables of the problem

```
cp_post(x = y + 1)
```

### Related topics

`cp_propagate` `AUTO_PROPAGATE` `cp_post`

## cp_propagate

#### Purpose

This function reaches a fixed point during constraint propagation. The constraint deduction rules are applied successively until no more deductions are possible. Note that propagating a constraint does not imply that the involved variables will be instantiated.

#### Synopsis

```
function cp_propagate :  boolean
```

#### Return value

Returns `true` if the propagation reaches a contradiction (infeasible problem), else returns `false`

#### Related topics

`cp_post` `auto_propagate`

## cp_find_next_sol

**Purpose**

Finds the next solution of the problem

**Synopsis**

```
function cp_find_next_sol : boolean
```

**Return value**

Returns `true` if an additional solution can be found, else `false`

**Example**

The following code shows how to scan all the solutions of a predefined problem containing b, x, y and z as decision variables:

```
while (cp_find_next_sol)
 writeln("b:", b, " x:", x, " y:", y, " z:", z)
```

**Related topics**

`cp_reset_search` `cp_minimize` `cp_maximize` `cp_set_branching`

## cp_reset_search

**Purpose**

This procedure resets the search process: it finalizes the tree search and returns to the first node of the tree. While it is not called, the branch and bound stays at a node in the tree search and the problem cannot be modified. It needs to be called only if tree search was not finished.

**Synopsis**

```
procedure cp_reset_search
```

# cp_maximise

### Purpose

Alias for cp_maximize. See `cp_maximize` for description.

### Synopsis

```
function cp_maximise(obj:cpvar) :  boolean
function cp_maximise(obj:cpfloatvar) :  boolean
```

### Related topics

`cp_maximize`

## cp_maximize

### Purpose

This function starts the search for an optimal solution of the problem that maximizes a specific variable. Upon termination of the search (when no limitation has been set on the search process), the last solution found (if any exists) is proven optimal.

### Synopsis

```
function cp_maximize(obj:cpvar) :  boolean
function cp_maximize :  boolean
```

### Argument

`obj` the decision variable to maximize

### Return value

`true` if a solution has been found, `false` if the problem is inconsistent (no solution exists)

### Example

The following code shows how to use this function to maximize the Benefit objective

```
optimizeProcess := cp_maximize(Benefit)
```

### Related topics

`cp_minimize` `cp_find_next_sol`

## cp_minimise

**Purpose**

Alias for cp_minimize. See cp_maximize for description.

**Synopsis**

```
function cp_minimise(obj:cpvar) :  boolean
function cp_minimise(obj:cpfloatvar) :  boolean
```

**Related topics**

cp_minimize

## cp_minimize

**Purpose**

This function starts the search for an optimal solution of the problem that minimizes a specific variable. Upon termination of the function (when no limitation has been set on the search process), the last solution found (if any exists) is proven optimal.

**Synopsis**

```
function cp_minimize(obj:cpvar) :  boolean
function cp_minimize(obj:cpfloatvar) :  boolean
```

**Argument**

`obj` the decision variable to minimize

**Return value**

`true` if a solution has been found, `false` if the problem is inconsistent (no solution exists)

**Example**

The following code shows how to use this function to minimize the Cost objective:

```
optimizeProcess := cp_minimize(Cost)
```

**Related topics**

`cp_maximize` `getsol` `cp_find_next_sol`

# getsol

## Purpose

This function returns the solution value of a variable or linear expression passed in argument. Note that the variable must be instantiated before calling this function, else it will return its lower bound.

## Synopsis

```
function getsol(x:cpvar) :  integer
function getsol(x:cpfloatvar) :  real
function getsol(l:cplinexp) :  integer
```

## Arguments

| | |
|---|---|
| `x` | a decision variable |
| `l` | a linear expression |

## Return value

The instantiation value of x (or by default its lower bound), respectively the evaluation of the linear expression

## Example

The following example shows how to get the solution value of a cpvar `x`

```
val:= getsol(X)
```

## Related topics

`getlb` `getub` `getsize` `is_fixed`

## cp_show_prob

### Purpose

This procedure prints an overview of the current state of the problem (variables and constraints)

### Synopsis

```
procedure cp_show_prob
```

### Related topics

`cp_show_var` `cp_show_stats`

## cp_show_sol

**Purpose**

This procedure prints an overview of the current solution.

**Synopsis**

```
procedure cp_show_sol
```

**Related topics**

cp_show_var cp_show_stats

## getname

**Purpose**

Gets the name of a variable / task / resource passed in argument. The name of the modeling object is used by problem and variable printing routines

**Synopsis**

```
procedure getname(var:cpvar)
procedure getname(fvar:cpfloatvar)
procedure getname(task:cptask)
procedure getname(resource:cpresource)
```

**Arguments**

`var` a finite domain variable

`fvar` the floating decision variable

`resource` a resource

`task` a task

**Example**

The following example shows how to print out the name of a cpvar x

```
writeln(getname(x))
```

**Related topics**

`setname` `cp_show_prob` `cp_show_var` `cp_show_schedule`

## setname

### Purpose

Sets the name of a variable / task / resource passed in argument, the name of the variable / task / resource is used by problem and variable printing routines

### Synopsis

```
procedure setname(var:cpvar,name:string)
procedure setname(fvar:cpfloatvar,name:string)
procedure setname(task:cptask,name:string)
procedure setname(resource:cpresource,name:string)
```

### Arguments

| | |
|---|---|
| `var` | a finite domain |
| `fvar` | a continuous variable |
| `task` | a task |
| `resource` | a resource |
| `name` | the name to set |

### Example

The following example shows how to set the name of a cpvar x to 'AMOUNT'

```
setname(x,"AMOUNT")
```

### Related topics

getname cp_show_prob cp_show_var cp_show_schedule

## cp_shave

### Purpose

Shaving consists in tentatively setting variables to a value in their domain. If the assignment fails (considering the complete constraint set), then this value can be removed from the domain, possibly eliminating many inconsistent values before starting search.

### Synopsis

```
function cp_shave:  boolean
```

### Return value

`false` if problem is proven to be inconsistent, `true` otherwise

### Example

The following example shows how to apply shaving to the variables of a problem:

```
res := cp_shave
```

### Related topics

cp_propagate

# cp_infeas_analysis

### Purpose

This method computes a minimal conflict set for an inconsistent problem. A minimal conflict set is a minimal size set of constraints that causes a contradiction (infeasibility).

### Synopsis

```
procedure cp_infeas_analysis
```

### Example

The following example shows how to compute a minimal conflict set:

```
...     ! constraint definition
cp_save_state
if (not cp_propagate) then
  cp_restore_state
  writeln("Problem is infeasible")
  cp_infeas_analysis
  exit(0)
end-if
cp_restore_state
...     ! problem solving
```

### Related topics

cp_save_state cp_restore_state

# cp_save_state

### Purpose
Save a marker in the CP solver stack.

### Synopsis
```
procedure cp_save_state
```

### Example
The following example shows how to save the state of a constraint system:

```
...      ! constraint definition
cp_save_state
if (not cp_propagate) then
  cp_restore_state
  writeln("Problem is infeasible")
  cp_infeas_analysis
  exit(0)
end-if
cp_restore_state
...      ! problem solving
```

### Related topics
cp_restore_state

## cp_restore_state

### Purpose

Restore the state of the CP solver at a previously saved state marker.

### Synopsis

```
procedure cp_restore_state
```

### Example

The following example shows how to restore the state of a constraint system:

```
...      ! constraint definition
cp_save_state
if (not cp_propagate) then
  cp_restore_state
  writeln("Problem is infeasible")
  cp_infeas_analysis
  exit(0)
end-if
cp_restore_state
...      ! problem solving
```

### Related topics

cp_save_state

## path_order

### Purpose

The path-heuristic is specifically designed to work in conjunction with the cycle constraint. It selects the first unassigned 'succ' variable in the order of the current subpath implied by the current values of the successors variables. When the subpath is empty (no 'succ' variables are currently instantiated) the path order-heuristic selects a node at random.

### Synopsis

```
function path_order(succ:array of cpvar, nodeSelection:string) :
      cpbranching
```

### Arguments

`succ` The list of successors variables

`nodeSelection` The value selection heuristic

### Related topics

`cycle`

# cp_local_optimize

### Purpose

This function starts the search for a near-optimal solution of the problem that optimizes a specific objective variable.

### Synopsis

```
function cp_local_optimize(obj:cpvar, minimize:  integer) :  boolean
function cp_local_optimize(obj:cpfloatvar, minimize:  integer) :  boolean
```

### Arguments

| | |
|---|---|
| `obj` | the objective variable |
| `minimize` | `1` for minimization or `0` for maximization |

### Related topics

`cp_minimize` `cp_maximize`

## set_sol_as_target

**Purpose**

Set the target values of all the variables to their value in the last solution found.

**Synopsis**

```
procedure set_sol_as_target
```

**Related topics**

gettarget settarget KALIS_NEAREST_VALUE

## cp_reset_params

**Purpose**

Reset parameters to their default value.

**Synopsis**

```
procedure cp_reset_params(parameterSet:integer)
```

**Argument**

`parameterSet` the set of parameters to reset (`KALIS_RESET_PARAMS_ALL`, `KALIS_RESET_VAR_BOUNDS`, `KALIS_RESET_VAR_PRECISION`, `KALIS_RESET_OPT_PARAMS`, `KALIS_RESET_SEARCH_PARAMS`)

**Example**

The following example shows how to use the cp_reset_params function to reset all parameters of Xpress-Kalis:

```
cp_reset_params(KALIS_RESET_PARAMS_ALL)
```

**Related topics**

`setparam`

## 9.5 Search

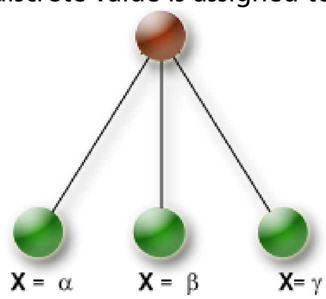


## assign_var

### Purpose

Creates an assign_var (Constraint programming style) branching scheme; in this scheme, a discrete value is assigned to the branching variable at each branch.




### Synopsis

```
function assign_var(varsel:string,valsel:string,variables:set of cpvar) :
      cpbranching
function assign_var(varsel:string,valsel:string,variables:array(range) of
      cpvar) :  cpbranching
function assign_var(varsel:string,valsel:string,variables:cpvarlist) :
      cpbranching
function assign_var(varsel:string,valsel:string) :  cpbranching
```

### Arguments

`varsel` name of the variable selector

`valsel` name of the value selector

`variables` list of variables to branch on

### Return value

assign_var branching scheme with default value and variable selector

### Example

The following example shows how to use an assign_var branching scheme during the search process

```
model "User branching"
 uses "kalis"

 parameters
  ALG=1
 end-parameters

 forward function varchoice(Vars: cpvarlist): integer
 forward function varchoice2(Vars: cpvarlist): integer
 forward function valchoice(x: cpvar): integer
 forward function valchoice2(x: cpvar): integer

 setparam("DEFAULT_LB", 0);
 setparam("DEFAULT_UB", 20)

 declarations
  R = 1..10
  y: array(R) of cpvar
  C: array(R) of integer
  Strategy: array(range) of cpbranching
```

```
 end-declarations

 C:: [4, 7, 2, 6, 9, 0,-1, 3, 8,-2]

 all_different(y)
 forall(i in R | isodd(i)) y(i) >= y(i+1) + 1
 y(4) + y(1) = 13; y(8) <= 15; y(7) <> 5

! Definition of user branching strategies:
 Strategy(1):= assign_and_forbid("varchoice2", "valchoice", y)
 Strategy(2):= assign_var("varchoice", "valchoice", y)
 Strategy(3):= split_domain("varchoice", "valchoice2", y, true, 2)
 Strategy(4):= split_domain("varchoice2", "valchoice", y, false, 5)

! Select a branching strategy
 cp_set_branching(Strategy(ALG))

 if cp_find_next_sol then
  forall(i in R) write(getsol(y(i)), " ")
  writeln
 end-if

!---------------------------------------------------------------
! **** Variable choice ****
! **** Choose variable with largest degree + smallest domain
 function varchoice(Vars: cpvarlist): integer
  declarations
   Vset,Iset: set of integer
  end-declarations

 ! Get the number of elements of "Vars"
  listsize:= getsize(Vars)

 ! Set on uninstantiated variables
  forall(i in 1..listsize)
   if not is_fixed(getvar(Vars,i)) then Vset+= {i}; end-if

  if Vset={} then
   returned:= 0
  else
  ! Get the variables with max. degree
   dmax:= max(i in Vset) getdegree(getvar(Vars,i))
   forall(i in Vset)
    if getdegree(getvar(Vars,i)) = dmax then Iset+= {i}; end-if
   dsize:= MAX_INT

  ! Choose var. with smallest domain among those indexed by 'Iset'
   forall(i in Iset)
    if getsize(getvar(Vars,i)) < dsize then
     returned:= i
     dsize:= getsize(getvar(Vars,i))
    end-if
  end-if
  writeln(returned)
 end-function
```

```
! **** Choose variable y(i) with smallest value of C(i)
 function varchoice2(Vars: cpvarlist): integer
  declarations
   Vset,Iset: set of integer
   VarInd: array(Iset) of integer
  end-declarations

 ! Set on uninstantiated variables
  listsize:= getsize(Vars)
  forall(i in 1..listsize)
   if not is_fixed(getvar(Vars,i)) then Vset+= {i}; end-if

  if getsize(Vset)=0 then
   returned:= 0
  else
  ! Establish a correspondence of indices between 'Vars' and 'y'
   forall(i in R)
    forall(j in Vset)
    if is_same(getvar(Vars,j), y(i)) then
     VarInd(i):= j
     Vset -= {j}
     break 1
    end-if

  ! Choose the variable
   imin:= min(i in Iset) i; cmin:= C(imin)
   forall(i in Iset)
    if C(i) < cmin then
     imin:= i; cmin:= C(i)
    end-if
   returned:= VarInd(imin)
  end-if
  writeln(imin, " ", returned)
 end-function

!-----------------------------------------------------------------
! *** Value choice ****
! **** Choose the next value one third larger than lower bound
! (Strategy may be used with any branching scheme since it
!  makes sure that the chosen value lies in the domain)
 function valchoice(x: cpvar): integer
!  returned:= getlb(x)
  returned:= getnext(x, getlb(x) + round((getub(x)-getlb(x))/3))
  writeln("Value: ", returned, " ", contains(x,returned),
          " x: ",  x)
 end-function

! **** Split the domain into lower third and upper two thirds
! (Strategy to be used only with 'split_domain' branching since
!  the chosen value may not be in the domain)
 function valchoice2(x: cpvar): integer
  returned:= getlb(x) + round((getub(x)-getlb(x))/3)
  writeln("Value: ", returned, " x: ", x)
 end-function
```

```
end-model
```

### Related topics

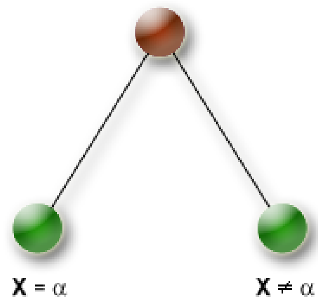
assign_and_forbid settle_disjunction probe_assign_var split_domain

## assign_and_forbid

**Purpose**

Creates an assign_and_forbid (MIP style) branching scheme; that will assign a value to the branching variable on one branch and forbid that value on the other branch.




**Synopsis**

```
function assign_and_forbid(varsel:string,valsel:string,variables:set of
      cpvar) : cpbranching
function assign_and_forbid(varsel:string,valsel:string,variables:array(range)
      of cpvar) : cpbranching
function assign_and_forbid(varsel:string,valsel:string,variables:cpvarlist)
      : cpbranching
function assign_and_forbid(varsel:string,valsel:string) : cpbranching
```

**Arguments**

`varsel` name of the variable selector

`valsel` name of the value selector

`variables` list of variables to branch on

**Return value**

assign_and_forbid branching scheme with value selector 'valsel' and variable selector 'varsel' working on all specified variables

**Example**

The following example shows how to use an assign_var branching scheme during the search process

```
model "User branching"
 uses "kalis"

 parameters
  ALG=1
 end-parameters

 forward function varchoice(Vars: cpvarlist): integer
 forward function varchoice2(Vars: cpvarlist): integer
 forward function valchoice(x: cpvar): integer
 forward function valchoice2(x: cpvar): integer

 setparam("DEFAULT_LB", 0);
 setparam("DEFAULT_UB", 20)

 declarations
  R = 1..10
```

```
  y: array(R) of cpvar
  C: array(R) of integer
  Strategy: array(range) of cpbranching
 end-declarations

 C:: [4, 7, 2, 6, 9, 0,-1, 3, 8,-2]

 all_different(y)
 forall(i in R | isodd(i)) y(i) >= y(i+1) + 1
 y(4) + y(1) = 13; y(8) <= 15; y(7) <> 5

! Definition of user branching strategies:
 Strategy(1):= assign_and_forbid("varchoice2", "valchoice", y)
 Strategy(2):= assign_var("varchoice", "valchoice", y)
 Strategy(3):= split_domain("varchoice", "valchoice2", y, true, 2)
 Strategy(4):= split_domain("varchoice2", "valchoice", y, false, 5)

! Select a branching strategy
 cp_set_branching(Strategy(ALG))

 if cp_find_next_sol then
  forall(i in R) write(getsol(y(i)), " ")
  writeln
 end-if

!----------------------------------------------------------------
! **** Variable choice ****
! **** Choose variable with largest degree + smallest domain
 function varchoice(Vars: cpvarlist): integer
  declarations
   Vset,Iset: set of integer
  end-declarations

 ! Get the number of elements of "Vars"
  listsize:= getsize(Vars)

 ! Set on uninstantiated variables
  forall(i in 1..listsize)
   if not is_fixed(getvar(Vars,i)) then Vset+= {i}; end-if

  if Vset={} then
   returned:= 0
  else
  ! Get the variables with max. degree
   dmax:= max(i in Vset) getdegree(getvar(Vars,i))
   forall(i in Vset)
    if getdegree(getvar(Vars,i)) = dmax then Iset+= {i}; end-if
   dsize:= MAX_INT

  ! Choose var. with smallest domain among those indexed by 'Iset'
   forall(i in Iset)
    if getsize(getvar(Vars,i)) < dsize then
     returned:= i
     dsize:= getsize(getvar(Vars,i))
    end-if
```

```
  end-if
  writeln(returned)
 end-function


! **** Choose variable y(i) with smallest value of C(i)
 function varchoice2(Vars: cpvarlist): integer
  declarations
   Vset,Iset: set of integer
   VarInd: array(Iset) of integer
  end-declarations

 ! Set on uninstantiated variables
  listsize:= getsize(Vars)
  forall(i in 1..listsize)
   if not is_fixed(getvar(Vars,i)) then Vset+= {i}; end-if

  if getsize(Vset)=0 then
   returned:= 0
  else
  ! Establish a correspondence of indices between 'Vars' and 'y'
   forall(i in R)
    forall(j in Vset)
    if is_same(getvar(Vars,j), y(i)) then
     VarInd(i):= j
     Vset -= {j}
     break 1
    end-if

  ! Choose the variable
   imin:= min(i in Iset) i; cmin:= C(imin)
   forall(i in Iset)
    if C(i) < cmin then
     imin:= i; cmin:= C(i)
    end-if
   returned:= VarInd(imin)
  end-if
  writeln(imin, " ", returned)
 end-function

!-----------------------------------------------------------------
! *** Value choice ****
! **** Choose the next value one third larger than lower bound
! (Strategy may be used with any branching scheme since it
!  makes sure that the chosen value lies in the domain)
 function valchoice(x: cpvar): integer
!  returned:= getlb(x)
  returned:= getnext(x, getlb(x) + round((getub(x)-getlb(x))/3))
  writeln("Value: ", returned, " ", contains(x,returned),
          " x: ",  x)
 end-function

! **** Split the domain into lower third and upper two thirds
! (Strategy to be used only with 'split_domain' branching since
!  the chosen value may not be in the domain)
```

```
 function valchoice2(x: cpvar): integer
  returned:= getlb(x) + round((getub(x)-getlb(x))/3)
  writeln("Value: ", returned, " x: ", x)
 end-function
end-model
```

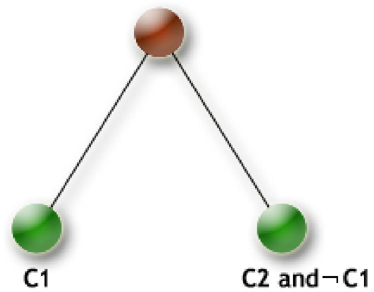
### Related topics

assign_var settle_disjunction probe_assign_var split_domain

## settle_disjunction

### Purpose

Creates a settle_disjunction branching scheme that resolves the status of all the disjunctions passed in argument. The branching consists in choosing one branch of the disjunction and posting the constraint stated by this branch. The branches are tested from left to right




### Synopsis

```
function settle_disjunction(constraints:set of cpctr) :  cpbranching
function settle_disjunction(constraints:array(range) of cpctr) :
      cpbranching
function settle_disjunction(constraints:set of cpctr) :  cpbranching
function settle_disjunction(constraints:array(range) of cpctr) :
      cpbranching
function settle_disjunction :  cpbranching
function settle_disjunction :  cpbranching
```

### Argument

`constraints` the disjunctions

### Return value

The resulting settle_disjunction branching scheme

### Example

The following example shows how to use the settle_disjunction branching scheme to solve a small disjunctive scheduling problem: The problem is to find a schedule for a set of tasks on one machine. The machine can process only one task at the time and the goal is to minimize the total weighted tardiness of the schedule.

```
model "Disjunctive scheduling with settle_disjunction"
uses "kalis"

 declarations
  NBTASKS = 5
  TASKS = 1..NBTASKS                        ! Set of tasks
  DUR: array(TASKS) of integer              ! Task durations
  DUE: array(TASKS) of integer              ! Due dates
  WEIGHT: array(TASKS) of integer           ! Weights of tasks
  start: array(TASKS) of cpvar              ! Start times
  tmp: array(TASKS) of cpvar                ! Aux. variable
  tardiness: array(TASKS) of cpvar          ! Tardiness
  twt: cpvar                                ! Objective variable
  zeroVar: cpvar                            ! 0-valued variable
  Strategy: array(range) of cpbranching     ! Branching strategy
  Disj: set of cpctr                        ! Disjunctions
 end-declarations
```

```
  DUR :: [21,53,95,55,34]
  DUE :: [66,101,232,125,150]
  WEIGHT :: [1,1,1,1,1]

  setname(twt, "Total weighted tardiness")
  zeroVar = 0
  setname(zeroVar, "zeroVar")

  forall (t in TASKS) do
   start(t) >= 0
   setname(start(t), "Start("+t+")")
   tmp(t) = start(t) + DUR(t) - DUE(t)
   setname(tardiness(t), "Tard("+t+")")
   tardiness(t) = maximum({tmp(t),zeroVar})
  end-do

  twt = sum(t in TASKS) (WEIGHT(t) * tardiness(t))

  ! Create the disjunctive constraints
  forall(t in 1..NBTASKS-1, s in t+1..NBTASKS)
   (start(t) + DUR(t) <= start(s)) or
   (start(s) + DUR(s) <= start(t))

  ! Define the branching strategy
  Strategy(1):= settle_disjunction
  Strategy(2):= split_domain(KALIS_LARGEST_MIN,KALIS_MIN_TO_MAX)
  cp_set_branching(Strategy)

  ! Solve the problem
  if not(cp_minimize(twt)) then
   writeln("Problem is inconsistent")
   exit(0)
  end-if

  forall (t in TASKS)
   writeln("[", getsol(start(t)), "==>",
           getsol(start(t)) + DUR(t), "]:\t ",
   getsol(tardiness(t)), "  (", getsol(tmp(t)), ")")
  writeln("Total weighted tardiness: ", getsol(twt))

end-model
```

### Related topics

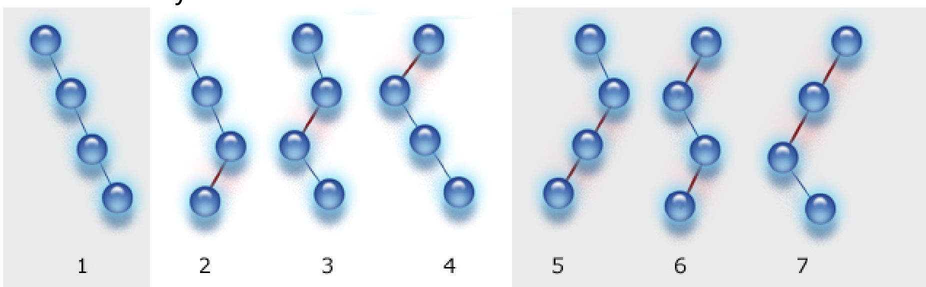
assign_var assign_and_forbid probe_assign_var split_domain

# probe_assign_var

### Purpose

Creates a probe_assign_var branching scheme, in which probing and assignment are applied simultaneously




### Synopsis

```
function probe_assign_var(varsel:string,valsel:string,variables:set of
      cpvar, probelevel:integer) :  cpbranching
function probe_assign_var(varsel:string, valsel:string,
      variables:array(range) of cpvar, probelevel:integer) :  cpbranching
function probe_assign_var(varsel:string, valsel:string,variables:cpvarlist,
      probelevel:integer) :  cpbranching
function probe_assign_var(varsel:string, valsel:string, probelevel:integer)
      :  cpbranching
function probe_assign_var(varsel:string,valsel:string) :  cpbranching
```

### Arguments

`varsel` the variable selector name (pre-defined constant or user-defined function name)

`valsel` the value selector (pre-defined constant or user-defined function name)

`variables` list of variables to branch on

`probelevel` maximal probing level

### Return value

The resulting probe_assign_var branching scheme

### Related topics

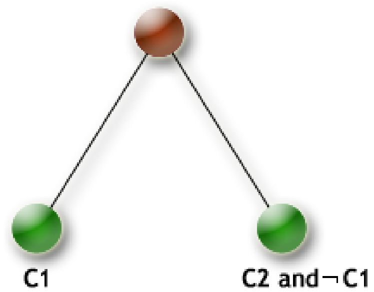
`assign_var` `assign_and_forbid` `settle_disjunction` `split_domain`

## probe_settle_disjunction

### Purpose

Creates a probe_settle_disjunction branching scheme that resolves the status of all the disjunctions passed in argument. The branching consists in choosing one branch of the disjunction and posting the constraint stated by this branch. The branches are tested from left to right




### Synopsis

```
function probe_settle_disjunction(disjunctions:set of cpctr,
      probeLevel:integer) :  cpbranching
function probe_settle_disjunction(disj_selector:string, disjunctions:set of
      cpctr, probeLevel:integer) :  cpbranching
function probe_settle_disjunction(disj_selector:string,
      disjunctions:array(range) of cpctr, probeLevel:integer) :
      cpbranching
function probe_settle_disjunction(disjunctions:array(range) of cpctr,
      probeLevel:integer) :  cpbranching
function probe_settle_disjunction(disj_selector:string, probeLevel:integer)
      :  cpbranching
function probe_settle_disjunction(probeLevel:integer) :  cpbranching
```

### Arguments

`disj_selector` the disjunction selector name (pre-defined constant or user-defined function name)

`disjunctions` the set or array of disjunctions

`probeLevel` maximal probing level

### Return value

The resulting probe_settle_disjunction branching scheme

### Example

The following example shows how to use the probe_settle_disjunction branching scheme to solve a small disjunctive scheduling problem:The problem consists of finding a schedule for some tasks on one machine. The machine can process only one task at the time and the goal is to minimize the total weighted tardiness of the schedule. Note that the result may be (and will be in this case) suboptimal as the search tree is not fully explored.

```
model "Disjunctive scheduling with probe_settle_disjunction"
 uses "kalis"

 declarations
  NBTASKS = 5
  TASKS = 1..NBTASKS                     ! Set of tasks
  DUR: array(TASKS) of integer           ! Task durations
  DUE: array(TASKS) of integer           ! Due dates
  WEIGHT: array(TASKS) of integer        ! Weights of tasks
```

```
 start: array(TASKS) of cpvar            ! Start times
 tmp: array(TASKS) of cpvar              ! Aux. variable
 tardiness: array(TASKS) of cpvar        ! Tardiness
 twt: cpvar                              ! Objective variable
 zeroVar: cpvar                          ! 0-valued variable
 Strategy: array(range) of cpbranching   ! Branching strategy
 Disj: set of cpctr                      ! Disjunctions
end-declarations

DUR :: [21,53,95,55,34]
DUE :: [66,101,232,125,150]
WEIGHT :: [1,1,1,1,1]

setname(twt, "Total weighted tardiness")
zeroVar = 0
setname(zeroVar, "zeroVar")

forall(t in TASKS) do
 start(t) >= 0
 start(t).name:= "Start("+t+")"
 tmp(t) = start(t) + DUR(t) - DUE(t)
 tardiness(t).name:= "Tard("+t+")"
 tardiness(t) = maximum({tmp(t),zeroVar})
end-do

twt = sum(t in TASKS) (WEIGHT(t) * tardiness(t))

! Create the disjunctive constraints
forall(t in 1..NBTASKS-1, s in t+1..NBTASKS)
  (start(t) + DUR(t) <= start(s)) or
  (start(s) + DUR(s) <= start(t))

! Define the branching strategy
Strategy(1):= probe_settle_disjunction(1)
Strategy(2):= split_domain(KALIS_LARGEST_MIN,KALIS_MIN_TO_MAX)
cp_set_branching(Strategy)

! Solve the problem
if not(cp_minimize(twt)) then
 writeln("problem is inconsistent")
 exit(0)
end-if

forall (t in TASKS)
 writeln("[", start(t).sol, "==>",
         start(t).sol + DUR(t), "]:\t ",
 tardiness(t).sol, "  (", tmp(t).sol, ")")
writeln("Total weighted tardiness: ", twt.sol)

end-model
```

### Related topics

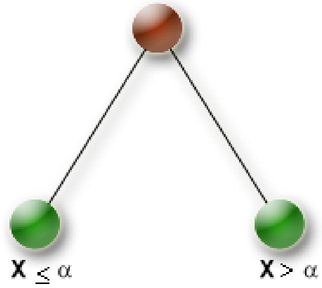
settle_disjunction probe_assign_var split_domain

## split_domain

### Purpose

Creates a split_domain branching scheme. This will split the domain of every branching variable X in two parts, one branch with the case X $\leq$ alpha and the other branch X >alpha where alpha is a value in the domain of X.




### Synopsis

```
function split_domain(varsel:string, valsel:string, variables:set of cpvar,
      leqfirst:boolean, stopsplit: integer) : cpbranching
function split_domain(varsel:string, valsel:string, variables:array(range)
      of cpvar, leqfirst:boolean, stopsplit: integer) : cpbranching
function split_domain(varsel:string, valsel:string, variables:cpvarlist,
      leqfirst:boolean, stopsplit: integer) : cpbranching
function split_domain(varsel:string, valsel:string, leqfirst:boolean,
      stopsplit: integer) : cpbranching
function split_domain(varsel:string, valsel:string) : cpbranching
function split_domain(varsel:string, valsel:string, variables:array(range)
      of cpvar, leqfirst:boolean, stopsplit: integer, probeLevel:integer)
      : cpbranching
function split_domain(varsel:string, valsel:string, variables:set of
      cpfloatvar, leqfirst:boolean, stopsplit: integer) : cpbranching
function split_domain(varsel:string, valsel:string, variables:array(range)
      of cpfloatvar, leqfirst:boolean, stopsplit: integer) : cpbranching
```

### Arguments

`varsel` the variable selector name (pre-defined constant or user-defined function name)

`valsel` the value selector (pre-defined constant or user-defined function name)

`variables` list of variables to branch on

`leqfirst` Explore the case $\leq$ first if `true`

`stopsplit` stop branching if the size of the domain of the variable is less than stopsplit

### Return value

split_domain branching scheme

### Example

The following example shows how to use a split_domain branching scheme during the search

```
model "User branching"
 uses "kalis"

 parameters
  ALG=1
 end-parameters

 forward function varchoice(Vars: cpvarlist): integer
```

```
 forward function varchoice2(Vars: cpvarlist): integer
 forward function valchoice(x: cpvar): integer
 forward function valchoice2(x: cpvar): integer

 setparam("DEFAULT_LB", 0);
 setparam("DEFAULT_UB", 20)

 declarations
  R = 1..10
  y: array(R) of cpvar
  C: array(R) of integer
  Strategy: array(range) of cpbranching
 end-declarations

 C:: [4, 7, 2, 6, 9, 0,-1, 3, 8,-2]

 all_different(y)
 forall(i in R | isodd(i)) y(i) >= y(i+1) + 1
 y(4) + y(1) = 13; y(8) <= 15; y(7) <> 5

! Definition of user branching strategies:
 Strategy(1):= assign_and_forbid("varchoice2", "valchoice", y)
 Strategy(2):= assign_var("varchoice", "valchoice", y)
 Strategy(3):= split_domain("varchoice", "valchoice2", y, true, 2)
 Strategy(4):= split_domain("varchoice2", "valchoice", y, false, 5)

! Select a branching strategy
 cp_set_branching(Strategy(ALG))

 if cp_find_next_sol then
  forall(i in R) write(getsol(y(i)), " ")
  writeln
 end-if

!---------------------------------------------------------------
! **** Variable choice ****
! **** Choose variable with largest degree + smallest domain
 function varchoice(Vars: cpvarlist): integer
  declarations
   Vset,Iset: set of integer
  end-declarations

 ! Get the number of elements of "Vars"
  listsize:= getsize(Vars)

 ! Set on uninstantiated variables
  forall(i in 1..listsize)
   if not is_fixed(getvar(Vars,i)) then Vset+= {i}; end-if

  if Vset={} then
   returned:= 0
  else
  ! Get the variables with max. degree
   dmax:= max(i in Vset) getdegree(getvar(Vars,i))
   forall(i in Vset)
```

```
   if getdegree(getvar(Vars,i)) = dmax then Iset+= {i}; end-if
  dsize:= MAX_INT

 ! Choose var. with smallest domain among those indexed by 'Iset'
  forall(i in Iset)
   if getsize(getvar(Vars,i)) < dsize then
    returned:= i
    dsize:= getsize(getvar(Vars,i))
   end-if
 end-if
 writeln(returned)
end-function


! **** Choose variable y(i) with smallest value of C(i)
function varchoice2(Vars: cpvarlist): integer
 declarations
  Vset,Iset: set of integer
  VarInd: array(Iset) of integer
 end-declarations

! Set on uninstantiated variables
 listsize:= getsize(Vars)
 forall(i in 1..listsize)
  if not is_fixed(getvar(Vars,i)) then Vset+= {i}; end-if

 if getsize(Vset)=0 then
  returned:= 0
 else
 ! Establish a correspondence of indices between 'Vars' and 'y'
  forall(i in R)
   forall(j in Vset)
   if is_same(getvar(Vars,j), y(i)) then
    VarInd(i):= j
    Vset -= {j}
    break 1
   end-if

 ! Choose the variable
  imin:= min(i in Iset) i; cmin:= C(imin)
  forall(i in Iset)
   if C(i) < cmin then
    imin:= i; cmin:= C(i)
   end-if
  returned:= VarInd(imin)
 end-if
 writeln(imin, " ", returned)
end-function

!----------------------------------------------------------------
! *** Value choice ****
! **** Choose the next value one third larger than lower bound
! (Strategy may be used with any branching scheme since it
!  makes sure that the chosen value lies in the domain)
function valchoice(x: cpvar): integer
```

```
!  returned:= getlb(x)
  returned:= getnext(x, getlb(x) + round((getub(x)-getlb(x))/3))
  writeln("Value: ", returned, " ", contains(x,returned),
          " x: ",  x)
 end-function

! **** Split the domain into lower third and upper two thirds
! (Strategy to be used only with 'split_domain' branching since
!  the chosen value may not be in the domain)
 function valchoice2(x: cpvar): integer
  returned:= getlb(x) + round((getub(x)-getlb(x))/3)
  writeln("Value: ", returned, " x: ", x)
 end-function
end-model
```

### Related topics

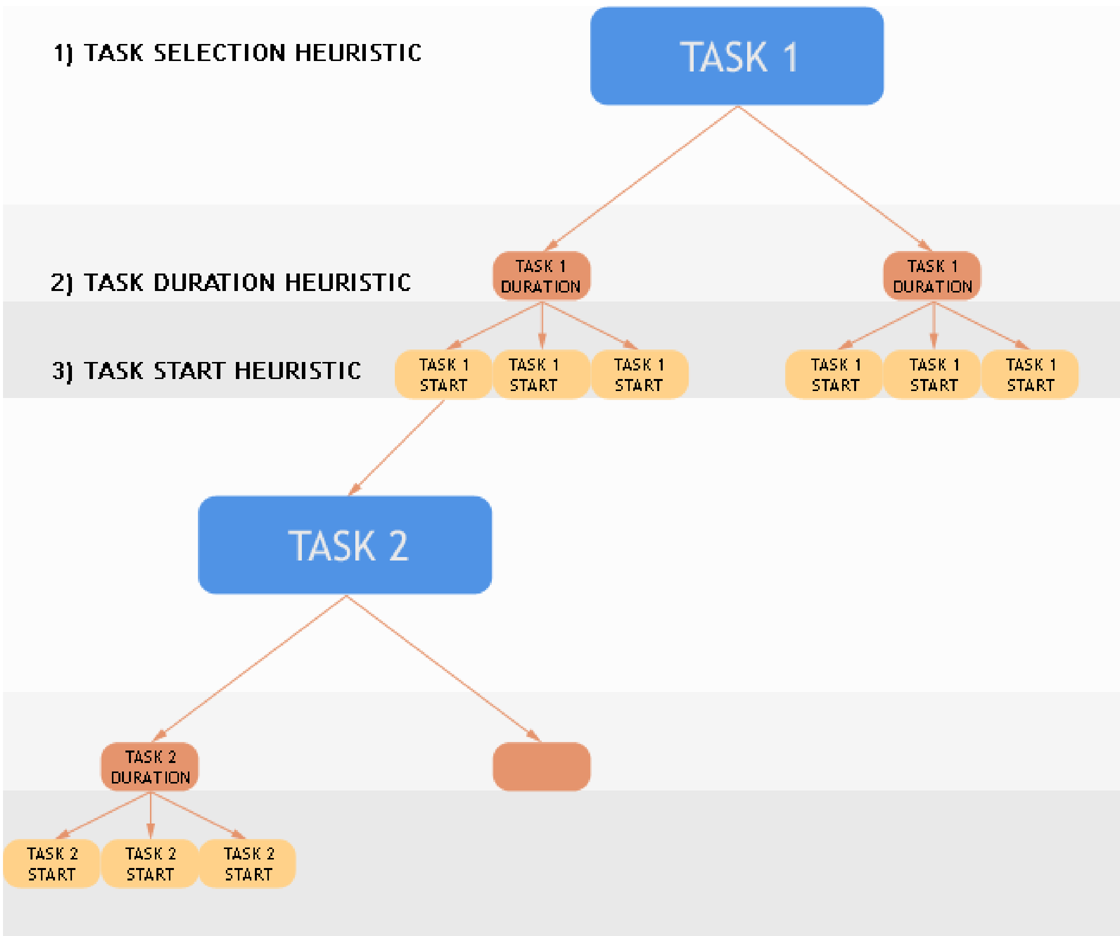
assign_var assign_and_forbid probe_assign_var settle_disjunction

## task_serialize

### Purpose

Creates a Task Serializer branching scheme that serializes the tasks passed in argument. The branching consists in choosing one task to schedule. Then a branch is created for each possible duration for this task. Once the duration is determined a branch is created for each posssible starting values for this task. When the start and the duration are fixed, the task is scheduled and the process is repeated until all the tasks are serialized.



### Synopsis

```
function task_serialize(taskSelector:string, durationHeuristic:string,
      startHeuristic:string, tasks:set of cptask) :  cpbranching
function task_serialize(taskSelector:string, durationHeuristic:string,
      startHeuristic:string, tasks:array of cptask) :  cpbranching
function task_serialize(taskSelector:string, durationHeuristic:string,
      startHeuristic:string, tasks:array of cptask, limit:integer) :
      cpbranching
function task_serialize(taskSelector:string, durationHeuristic:string,
      startHeuristic:string, tasks:array of cptask, limit:integer) :
      cpbranching
function task_serialize(taskSelector:string, durationHeuristic:string,
      startHeuristic:string, tasks:array of cptask, limit:integer) :
      cpbranching
function task_serialize(taskSelector:string, durationHeuristic:string,
      startHeuristic:string, tasks:array of cptask, limit:integer) :
      cpbranching
```

### Arguments

`taskSelector` the task selector

`durationHeuristic` the task duration assignment heuristic

`startHeuristic` the task start time assignment heuristic

`tasks` the set of tasks to be serialized.

### Return value

The resulting Task Serializer branching scheme

### Example

The following example shows how to use the task_serialize branching scheme to solve a small cumulative scheduling problem:

```
*******************************************************************!)
model "Tasks serialization example"
 uses "kalis"

 declarations
  Masonry, Carpentry, Roofing, Windows, Facade, Garden, Plumbing,
    Ceiling, Painting, MovingIn : cptask     ! Declaration of tasks
  taskset : set of cptask
  money_available : cpresource               ! Resource declaration
 end-declarations

 forward function selectNextTask(tasks: cptasklist) : integer

! 'money_available' is a cumulative resource with max. amount of 29$
 set_resource_attributes(money_available,KALIS_DISCRETE_RESOURCE,29)

! Limit resource availability to 20$ in the time interval [0,14]
 setcapacity( money_available, 0, 14, 20 )

! Setting the task durations and predecessor sets
 set_task_attributes(Masonry   , 7 )
 set_task_attributes(Carpentry, 3, {Masonry} )
 set_task_attributes(Roofing  , 1, {Carpentry} )
 set_task_attributes(Windows  , 1, {Roofing} )
 set_task_attributes(Facade   , 2, {Roofing} )
```

```
 set_task_attributes(Garden   , 1, {Roofing} )
 set_task_attributes(Plumbing , 8, {Masonry} )
 set_task_attributes(Ceiling  , 3, {Masonry} )
 set_task_attributes(Painting , 2, {Ceiling} )
 set_task_attributes(MovingIn , 1, {Windows,Facade,Garden,Painting})

! Setting the resource consumptions
 consumes(Masonry  , 7, money_available )
 consumes(Carpentry, 3, money_available )
 consumes(Roofing  , 1, money_available )
 consumes(Windows  , 1, money_available )
 consumes(Facade   , 2, money_available )
 consumes(Garden   , 1, money_available )
 consumes(Plumbing , 8, money_available )
 consumes(Ceiling  , 3, money_available )
 consumes(Painting , 2, money_available )
 consumes(MovingIn , 1, money_available )

! Set of tasks to schedule
 taskset := {Masonry, Carpentry, Roofing, Windows, Facade, Garden,
             Plumbing, Ceiling, Painting, MovingIn}

! Set the custom branching strategy using task_serialize:
! - the task serialization process will use the function
!   "selectNextTask" to look for the next task to fix
! - it will use the "KALIS_MAX_TO_MIN" value selection heuristic
!   to set the tasks duration variable
! - and the "KALIS_MIN_TO_MAX" value selection heuristic to set
!   the start of the task
 cp_set_branching(task_serialize("selectNextTask",
                  KALIS_MAX_TO_MIN, KALIS_MIN_TO_MAX, taskset))

! Find the optimal schedule (minimizing the makespan)
 if (0 <> cp_schedule(getmakespan)) then
   cp_show_sol
 else
   writeln("No solution found")
 end-if

!-------------------------------------------------------------
! **** Function to select the next task to schedule
 function selectNextTask(tasks: cptasklist) : integer
  write("selectNextTask : ")
  declarations
   Vset,Iset: set of integer
  end-declarations

 ! Get the number of elements of "tasks"
  listsize:= getsize(tasks)

 ! Set of uninstantiated variables
  forall(i in 1..listsize)
   if not is_fixed(getstart(gettask(tasks,i))) or
      not is_fixed(getduration(gettask(tasks,i))) then
     Vset+= {i};
```

```
   end-if

  if Vset={} then
    returned:= 0
  else
  ! Get the variables with max. degree
    dmax:= max(i in Vset) getsize(getduration(gettask(tasks,i)))
    forall(i in Vset)
      if getsize(getduration(gettask(tasks,i))) = dmax then
       Iset+= {i}; end-if
    dsize:= MAX_INT

  ! Choose var. with smallest domain among those indexed by 'Iset'
    forall(i in Iset)
      if getsize(getstart(gettask(tasks,i))) < dsize then
        returned:= i
        dsize:= getsize(getstart(gettask(tasks,i)))
      end-if
  end-if

  if (returned <> 0) then
   writeln(gettask(tasks,returned))
  end-if
 end-function

end-model
```

### Related topics

assign_var assign_and_forbid probe_assign_var split_domain

## cp_set_branching

### Purpose

Sets the branching strategy to use during the search for a solution; please refer to the 'Paradigm' section of this reference manual for further details.

### Synopsis

```
procedure cp_set_branching
procedure cp_set_branching(Strategy:cpbranching)
procedure cp_set_branching(Strategy:array(range) of cpbranching)
```

### Argument

`Strategy` a branching strategy (single cpbranching or cpbranching array)

### Example

The following example shows how to set the search strategy:

```
model "User branching"
 uses "kalis"

 parameters
  ALG=1
 end-parameters

 forward function varchoice(Vars: cpvarlist): integer
 forward function varchoice2(Vars: cpvarlist): integer
 forward function valchoice(x: cpvar): integer
 forward function valchoice2(x: cpvar): integer

 setparam("DEFAULT_LB", 0);
 setparam("DEFAULT_UB", 20)

 declarations
  R = 1..10
  y: array(R) of cpvar
  C: array(R) of integer
  Strategy: array(range) of cpbranching
 end-declarations

 C:: [4, 7, 2, 6, 9, 0,-1, 3, 8,-2]

 all_different(y)
 forall(i in R | isodd(i)) y(i) >= y(i+1) + 1
 y(4) + y(1) = 13; y(8) <= 15; y(7) <> 5

! Definition of user branching strategies:
 Strategy(1):= assign_and_forbid("varchoice2", "valchoice", y)
 Strategy(2):= assign_var("varchoice", "valchoice", y)
 Strategy(3):= split_domain("varchoice", "valchoice2", y, true, 2)
 Strategy(4):= split_domain("varchoice2", "valchoice", y, false, 5)

! Select a branching strategy
 cp_set_branching(Strategy(ALG))

 if cp_find_next_sol then
  forall(i in R) write(getsol(y(i)), " ")
```

```
  writeln
 end-if

!-----------------------------------------------------------------
! **** Variable choice ****
! **** Choose variable with largest degree + smallest domain
 function varchoice(Vars: cpvarlist): integer
  declarations
   Vset,Iset: set of integer
  end-declarations

 ! Get the number of elements of "Vars"
  listsize:= getsize(Vars)

 ! Set on uninstantiated variables
  forall(i in 1..listsize)
   if not is_fixed(getvar(Vars,i)) then Vset+= {i}; end-if

  if Vset={} then
   returned:= 0
  else
  ! Get the variables with max. degree
   dmax:= max(i in Vset) getdegree(getvar(Vars,i))
   forall(i in Vset)
    if getdegree(getvar(Vars,i)) = dmax then Iset+= {i}; end-if
   dsize:= MAX_INT

  ! Choose var. with smallest domain among those indexed by 'Iset'
   forall(i in Iset)
    if getsize(getvar(Vars,i)) < dsize then
     returned:= i
     dsize:= getsize(getvar(Vars,i))
    end-if
  end-if
  writeln(returned)
 end-function


! **** Choose variable y(i) with smallest value of C(i)
 function varchoice2(Vars: cpvarlist): integer
  declarations
   Vset,Iset: set of integer
   VarInd: array(Iset) of integer
  end-declarations

 ! Set on uninstantiated variables
  listsize:= getsize(Vars)
  forall(i in 1..listsize)
   if not is_fixed(getvar(Vars,i)) then Vset+= {i}; end-if

  if getsize(Vset)=0 then
   returned:= 0
  else
  ! Establish a correspondence of indices between 'Vars' and 'y'
   forall(i in R)
```

```
    forall(j in Vset)
    if is_same(getvar(Vars,j), y(i)) then
     VarInd(i):= j
     Vset -= {j}
     break 1
    end-if

  ! Choose the variable
   imin:= min(i in Iset) i; cmin:= C(imin)
   forall(i in Iset)
    if C(i) < cmin then
     imin:= i; cmin:= C(i)
    end-if
   returned:= VarInd(imin)
  end-if
  writeln(imin, " ", returned)
 end-function

!----------------------------------------------------------------
! *** Value choice ****
! **** Choose the next value one third larger than lower bound
! (Strategy may be used with any branching scheme since it
!  makes sure that the chosen value lies in the domain)
 function valchoice(x: cpvar): integer
!  returned:= getlb(x)
  returned:= getnext(x, getlb(x) + round((getub(x)-getlb(x))/3))
  writeln("Value: ", returned, " ", contains(x,returned),
          " x: ",  x)
 end-function

! **** Split the domain into lower third and upper two thirds
! (Strategy to be used only with 'split_domain' branching since
!  the chosen value may not be in the domain)
 function valchoice2(x: cpvar): integer
  returned:= getlb(x) + round((getub(x)-getlb(x))/3)
  writeln("Value: ", returned, " x: ", x)
 end-function
end-model
```

## Related topics

settle_disjunction assign_var assign_and_forbid split_domain Chapter 4

# cp_show_stats

### Purpose

This procedure prints some statistics about the search process (time elapsed, number of nodes, depth, number of backtracks)

### Synopsis

```
procedure cp_show_stats
```

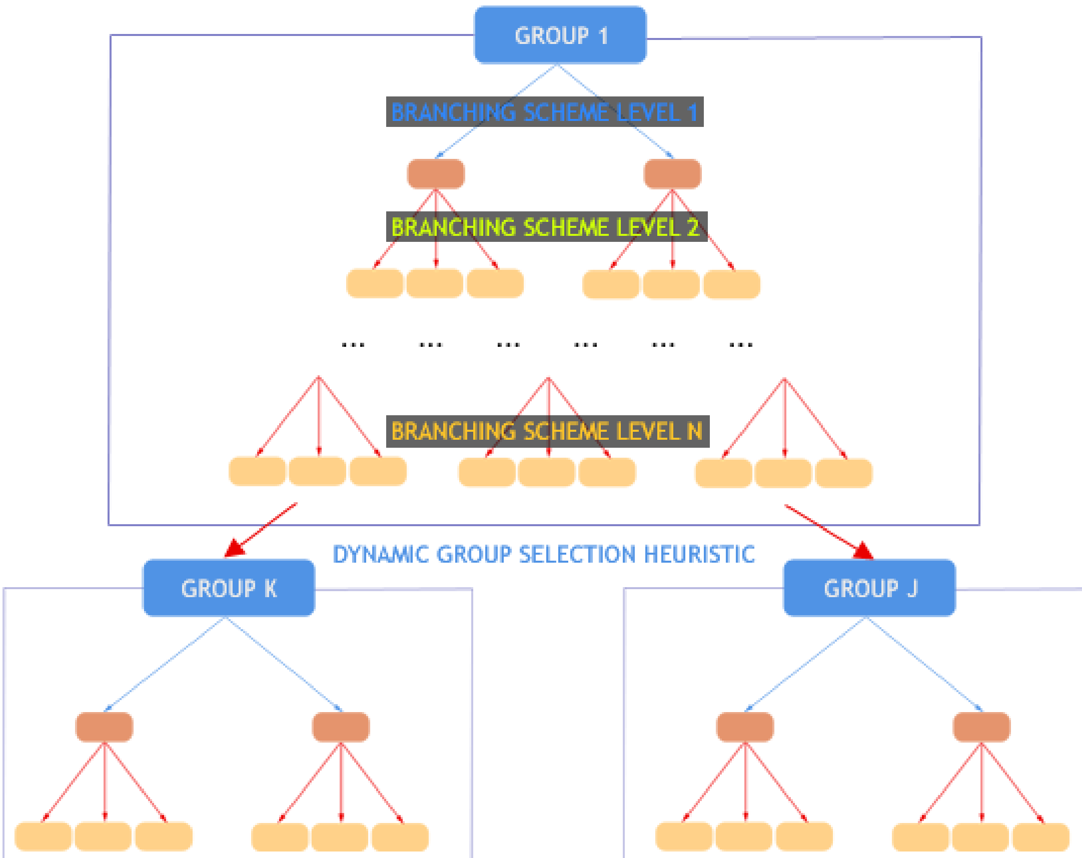
### Related topics

`cp_show_prob` `cp_show_var`

# bs_group

### Purpose

Create a group of branching schemes. A group of branching schemes is an ordered list of branching schemes. It is used as input to the `bs_group_serializer` branching scheme. A user 'tag' information can be associated with a group in order to link this group to a specific user structure.




### Synopsis

```
function bs_group(branchings:  array of cpbranching, tag:integer) :
        cpbsgroup
```

### Arguments

`branchings` the branching schemes forming the group

`tag` tag associated with the branching scheme group (use and interpretation entirely up to the user)

### Related topics

`group_serializer`

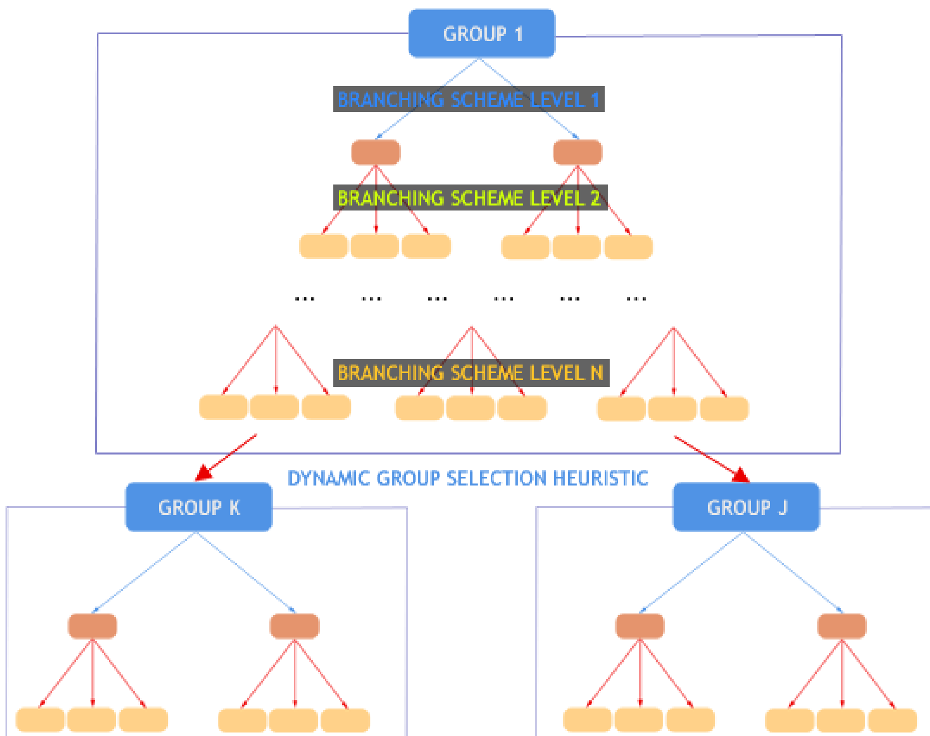
# group_serializer

## Purpose

A branching scheme Group Serializer is a branching scheme of branching schemes. That means, it can be seen as a meta-branching scheme. The search can be decomposed into clusters of branching schemes that will be explored based upon a specific dynamic group selection heuristic. When a specific group is selected, the ordered branching scheme list of this group will be treated sequentially. Once all the branching schemes of the group have been treated, another branching scheme group is selected with the group selection heuristic.
For example, the task_serializer branching scheme is a particular kind of group serializer heuristic tailored for task based search tree exploration. In this case a group corresponds to a task and the list of branching schemes is the following :

1. start time variable
2. duration variable

.




## Synopsis

```
function group_serializer(groups:  set of cpbsgroup, groupSelector:
       string) :  cpbranching
function group_serializer(groups:  set of cpbsgroup, groupSelector:
       string, probe:  integer) :  cpbranching
```

## Arguments

`groups` the set of branching scheme groups

`groupselector` the group selection heuristic

`probe` the probe level

## Related topics

`bs_group`

## gettag

**Purpose**

Get the tag associated with the branching scheme group passed in argument. The tag is defined by the user when creating the group (see `bs_group`).

**Synopsis**

```
function gettag(group: cpbsgroup) : integer
```

**Argument**

`group` the set of branching scheme groups

**Related topics**

`group_serializer` `bs_group`

## 9.6 Callbacks



## cp_set_solution_callback

**Purpose**

Sets the solution callback procedure that will be called each time that a solution has been found by the solver. Note that this callback procedure does not take any argument.

**Synopsis**

```
procedure cp_set_solution_callback(callbackName:string)
```

**Argument**

`callbackName` the name of the procedure to call

**Example**

The following example shows how to use the solution callback:

```
model "Using callbacks"
 uses "kalis"

 declarations
  NBTASKS = 5
  TASKS = 1..NBTASKS                         ! Set of tasks
  DUR: array(TASKS) of integer               ! Task durations
  DURs: array(set of cpvar) of integer       ! Durations
  DUE: array(TASKS) of integer               ! Due dates
  WEIGHT: array(TASKS) of integer            ! Weights of tasks
  start: array(TASKS) of cpvar               ! Start times
  tmp: array(TASKS) of cpvar                 ! Aux. variable
  tardiness: array(TASKS) of cpvar           ! Tardiness
  twt: cpvar                                 ! Objective variable
  zeroVar: cpvar                             ! 0-valued variable
  Strategy: array(range) of cpbranching      ! Branching strategy
  Disj: set of cpctr                         ! Disjunctions
  nodesx: array(range) of integer            ! x-coordinates
  nodesy: array(range) of integer            ! y-coordinates
  currentpos: integer
 end-declarations

! Initialization of search tree data
 nodesx(0) := 1
 nodesy(0) := 0
 currentpos := 1

! **********************************************************
! solution_found: called each time a solution is found
! **********************************************************
 procedure solution_found
  writeln("A solution has been found :")
  forall (t in TASKS)
   writeln("[", getsol(start(t)), "==>",
           (getsol(start(t)) + DUR(t)), "]:\t ",
           getsol(tardiness(t)), "  (", getsol(tmp(t)), ")")
  writeln("Total weighted tardiness: ", getsol(twt))
 end-procedure

! **********************************************************
! node_explored: called each time a node is explored
```

```
! ******************************************************
 procedure node_explored
  nodesx(currentpos) += 1
  if (nodesx(currentpos-1)>nodesx(currentpos)) then
   nodesx(currentpos) := nodesx(currentpos-1)
  end-if
  nodesy(currentpos) := -currentpos
  writeln("[Node explored depth : " , (-nodesy(currentpos)), "]")
 end-procedure

! ******************************************************
! go_down_branch: called each time the search goes down
!                 a branch of the search tree
! ******************************************************
 procedure go_down_branch
  writeln("[Branch go_down " , (-nodesy(currentpos)) , "]")
  currentpos := currentpos + 1
 end-procedure

! ******************************************************
! go_up_branch: called each time the search goes up
!               a branch of the search tree
! ******************************************************
 procedure go_up_branch
  currentpos := currentpos - 1
  writeln("[Branch go_up " , (-nodesy(currentpos)) , "]")
 end-procedure

! ******************************************************
! Problem definition
! ******************************************************

 DUR :: [21,53,95,55,34]
 DUE :: [66,101,232,125,150]
 WEIGHT :: [1,1,1,1,1]

 setname(twt, "Total weighted tardiness")
 zeroVar = 0
 setname(zeroVar, "zeroVar")

! Setting up the decision variables
 forall (t in TASKS) do
  start(t) >= 0
  setname(start(t), "Start("+t+")")
  DURs(start(t)):= DUR(t)
  tmp(t) = start(t) + DUR(t) - DUE(t)
  setname(tardiness(t), "Tard("+t+")")
  tardiness(t) = maximum({tmp(t), zeroVar})
 end-do

 twt = sum(t in TASKS) (WEIGHT(t) * tardiness(t))

 ! Create the disjunctive constraints
 disjunctive(union(t in TASKS) {start(t)}, DURs, Disj, 1)
```

```
 ! The setxxxcallback methods must be called before
 ! setting the branching with 'cp_set_branching'
 cp_set_solution_callback("solution_found")
 cp_set_node_callback("node_explored")
 cp_set_branch_callback("go_down_branch", "go_up_branch")

 Strategy(0):= settle_disjunction
 Strategy(1):= split_domain(KALIS_MAX_DEGREE,KALIS_MIN_TO_MAX)
 cp_set_branching(Strategy)

 if not(cp_minimize(twt)) then
  writeln("problem is inconsistent")
  exit(0)
 end-if

end-model
```

### Related topics

getsol cp_set_node_callback cp_set_branch_callback

## cp_set_node_callback

**Purpose**

Sets the node callback procedure that will be called each time that a node is explored by the search algorithm. Note that this callback procedure does not take any argument.

**Synopsis**

```
procedure cp_set_node_callback(callbackName:string)
```

**Argument**

`callbackName` the name of the procedure to call

**Example**

The following example (using IVE) shows how to use the node callback:

```
model "Using callbacks"
 uses "kalis"

 declarations
  NBTASKS = 5
  TASKS = 1..NBTASKS                          ! Set of tasks
  DUR: array(TASKS) of integer                ! Task durations
  DURs: array(set of cpvar) of integer        ! Durations
  DUE: array(TASKS) of integer                ! Due dates
  WEIGHT: array(TASKS) of integer             ! Weights of tasks
  start: array(TASKS) of cpvar                ! Start times
  tmp: array(TASKS) of cpvar                  ! Aux. variable
  tardiness: array(TASKS) of cpvar            ! Tardiness
  twt: cpvar                                  ! Objective variable
  zeroVar: cpvar                              ! 0-valued variable
  Strategy: array(range) of cpbranching       ! Branching strategy
  Disj: set of cpctr                          ! Disjunctions
  nodesx: array(range) of integer             ! x-coordinates
  nodesy: array(range) of integer             ! y-coordinates
  currentpos: integer
 end-declarations

! Initialization of search tree data
 nodesx(0) := 1
 nodesy(0) := 0
 currentpos := 1

! **********************************************************
! solution_found: called each time a solution is found
! **********************************************************
 procedure solution_found
  writeln("A solution has been found :")
  forall (t in TASKS)
   writeln("[", getsol(start(t)), "==>",
            (getsol(start(t)) + DUR(t)), "]:\t ",
            getsol(tardiness(t)), "  (", getsol(tmp(t)), ")")
  writeln("Total weighted tardiness: ", getsol(twt))
 end-procedure

! **********************************************************
! node_explored: called each time a node is explored
```

```
! ***********************************************************
 procedure node_explored
  nodesx(currentpos) += 1
  if (nodesx(currentpos-1)>nodesx(currentpos)) then
   nodesx(currentpos) := nodesx(currentpos-1)
  end-if
  nodesy(currentpos) := -currentpos
  writeln("[Node explored depth : " , (-nodesy(currentpos)), "]")
 end-procedure

! ***********************************************************
! go_down_branch: called each time the search goes down
!                 a branch of the search tree
! ***********************************************************
 procedure go_down_branch
  writeln("[Branch go_down " , (-nodesy(currentpos)) , "]")
  currentpos := currentpos + 1
 end-procedure

! ***********************************************************
! go_up_branch: called each time the search goes up
!               a branch of the search tree
! ***********************************************************
 procedure go_up_branch
  currentpos := currentpos - 1
  writeln("[Branch go_up " , (-nodesy(currentpos)) , "]")
 end-procedure

! ***********************************************************
! Problem definition
! ***********************************************************

 DUR :: [21,53,95,55,34]
 DUE :: [66,101,232,125,150]
 WEIGHT :: [1,1,1,1,1]

 setname(twt, "Total weighted tardiness")
 zeroVar = 0
 setname(zeroVar, "zeroVar")

! Setting up the decision variables
 forall (t in TASKS) do
  start(t) >= 0
  setname(start(t), "Start("+t+")")
  DURs(start(t)):= DUR(t)
  tmp(t) = start(t) + DUR(t) - DUE(t)
  setname(tardiness(t), "Tard("+t+")")
  tardiness(t) = maximum({tmp(t), zeroVar})
 end-do

 twt = sum(t in TASKS) (WEIGHT(t) * tardiness(t))

 ! Create the disjunctive constraints
 disjunctive(union(t in TASKS) {start(t)}, DURs, Disj, 1)
```

```
  ! The setxxxcallback methods must be called before
  ! setting the branching with 'cp_set_branching'
  cp_set_solution_callback("solution_found")
  cp_set_node_callback("node_explored")
  cp_set_branch_callback("go_down_branch", "go_up_branch")

  Strategy(0):= settle_disjunction
  Strategy(1):= split_domain(KALIS_MAX_DEGREE,KALIS_MIN_TO_MAX)
  cp_set_branching(Strategy)

  if not(cp_minimize(twt)) then
   writeln("problem is inconsistent")
   exit(0)
  end-if

end-model
```

**Related topics**

getsol cp_set_solution_callback cp_set_branch_callback

## cp_set_branch_callback

**Purpose**

Sets the branch callback procedure that will be called each time that a branch is explored by the search algorithm. Note that this callback procedure does not take any argument.

**Synopsis**

```
procedure cp_set_branch_callback(callbackNameDown:string,
      callbackNameUp:string)
```

**Argument**

`callbackNameDown, callbackNameUp` the name of the procedure to call, in the case the branch is explored downward (resp. upward)

**Example**

The following example shows how to use the branch callback:

```
model "Using callbacks"
 uses "kalis"

 declarations
  NBTASKS = 5
  TASKS = 1..NBTASKS                        ! Set of tasks
  DUR: array(TASKS) of integer              ! Task durations
  DURs: array(set of cpvar) of integer      ! Durations
  DUE: array(TASKS) of integer              ! Due dates
  WEIGHT: array(TASKS) of integer           ! Weights of tasks
  start: array(TASKS) of cpvar              ! Start times
  tmp: array(TASKS) of cpvar                ! Aux. variable
  tardiness: array(TASKS) of cpvar          ! Tardiness
  twt: cpvar                                ! Objective variable
  zeroVar: cpvar                            ! 0-valued variable
  Strategy: array(range) of cpbranching     ! Branching strategy
  Disj: set of cpctr                        ! Disjunctions
  nodesx: array(range) of integer           ! x-coordinates
  nodesy: array(range) of integer           ! y-coordinates
  currentpos: integer
 end-declarations

! Initialization of search tree data
 nodesx(0) := 1
 nodesy(0) := 0
 currentpos := 1

! **********************************************************
! solution_found: called each time a solution is found
! **********************************************************
 procedure solution_found
  writeln("A solution has been found :")
  forall (t in TASKS)
   writeln("[", getsol(start(t)), "==>",
           (getsol(start(t)) + DUR(t)), "]:\t ",
           getsol(tardiness(t)), "  (", getsol(tmp(t)), ")")
  writeln("Total weighted tardiness: ", getsol(twt))
 end-procedure
```

```
! ********************************************************
! node_explored: called each time a node is explored
! ********************************************************
 procedure node_explored
  nodesx(currentpos) += 1
  if (nodesx(currentpos-1)>nodesx(currentpos)) then
   nodesx(currentpos) := nodesx(currentpos-1)
  end-if
  nodesy(currentpos) := -currentpos
  writeln("[Node explored depth : " , (-nodesy(currentpos)), "]")
 end-procedure

! ********************************************************
! go_down_branch: called each time the search goes down
!                 a branch of the search tree
! ********************************************************
 procedure go_down_branch
  writeln("[Branch go_down " , (-nodesy(currentpos)) , "]")
  currentpos := currentpos + 1
 end-procedure

! ********************************************************
! go_up_branch: called each time the search goes up
!               a branch of the search tree
! ********************************************************
 procedure go_up_branch
  currentpos := currentpos - 1
  writeln("[Branch go_up " , (-nodesy(currentpos)) , "]")
 end-procedure

! ********************************************************
! Problem definition
! ********************************************************

 DUR :: [21,53,95,55,34]
 DUE :: [66,101,232,125,150]
 WEIGHT :: [1,1,1,1,1]

 setname(twt, "Total weighted tardiness")
 zeroVar = 0
 setname(zeroVar, "zeroVar")

! Setting up the decision variables
 forall (t in TASKS) do
  start(t) >= 0
  setname(start(t), "Start("+t+")")
  DURs(start(t)):= DUR(t)
  tmp(t) = start(t) + DUR(t) - DUE(t)
  setname(tardiness(t), "Tard("+t+")")
  tardiness(t) = maximum({tmp(t), zeroVar})
 end-do

 twt = sum(t in TASKS) (WEIGHT(t) * tardiness(t))

 ! Create the disjunctive constraints
```

```
 disjunctive(union(t in TASKS) {start(t)}, DURs, Disj, 1)

 ! The setxxxcallback methods must be called before
 ! setting the branching with 'cp_set_branching'
 cp_set_solution_callback("solution_found")
 cp_set_node_callback("node_explored")
 cp_set_branch_callback("go_down_branch", "go_up_branch")

 Strategy(0):= settle_disjunction
 Strategy(1):= split_domain(KALIS_MAX_DEGREE,KALIS_MIN_TO_MAX)
 cp_set_branching(Strategy)

 if not(cp_minimize(twt)) then
  writeln("problem is inconsistent")
  exit(0)
 end-if

end-model
```

### Related topics

getsol cp_set_solution_callback cp_set_node_callback

## 9.7 Scheduling

## is_fixed

### Purpose

Returns `true` if the task passed in argument has its start and completion times fixed.

### Synopsis

```
function is_fixed(task:cptask) :  boolean
```

### Argument

`task` the task

### Return value

`true` if task is fixed

### Example

The following example shows how to see if a cptask `task` is fixed

```
if is_fixed(task) then
 write('task is fixed! ')
end-if
```

### Related topics

getlb getub getmiddle getsize getval getdegree gettarget getrand getnext getprev contains

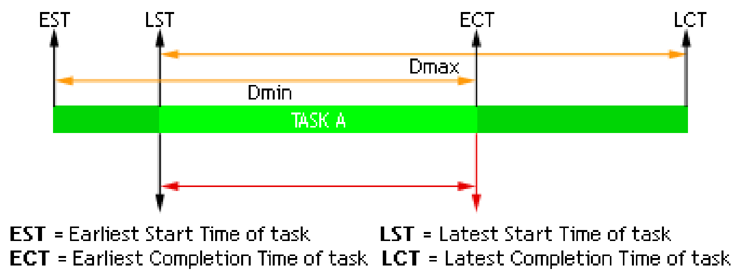
# set_task_attributes

## Purpose

Sets some attributes for a task.
A cptask is represented by three cpvar:

- start representing the start time of the task
- end representing the completion time of the task
- duration representing the duration of the task.

These three structural variables are linked with the following constraint: task + duration $\leq$ end. The start time variable represents two specific parameters of the task: the Earliest Start Time (EST, represented by its lower bound) and its Latest Start Time (LST, represented by its upper bound). The end variable represents another two parameters of the task: the Earliest Completion Time (ECT, represented by its lower bound) and its Latest Completion Time (LCT, represented by its upper bound). The duration variable represents the following two parameters of the task: the minimum task duration (Dmin, represented by its lower bound) and the maximum task duration (Dmax, represented by its upper bound). The graphic below illustrates these properties:




## Synopsis

```
procedure set_task_attributes(task:cptask, duration:integer,
       resource:cpresource, precedences:set of cptask)
procedure set_task_attributes(task:cptask, duration:integer,
       resource:cpresource)
procedure set_task_attributes(task:cptask, duration:integer)
procedure set_task_attributes(task:cptask, duration:integer,
       precedences:set of cptask)
procedure set_task_attributes(task:cptask, resource:cpresource,
       requirement:integer)
```

## Arguments

`task` the task to set attributes

`duration` the duration of the task

`precedences` the set of tasks that must precede t in the schedule

`resource` a resource that is required during the execution of the task

`requirement` amount of the specified resource required per time unit

## Example

The following example shows how to set some attributes of a task:

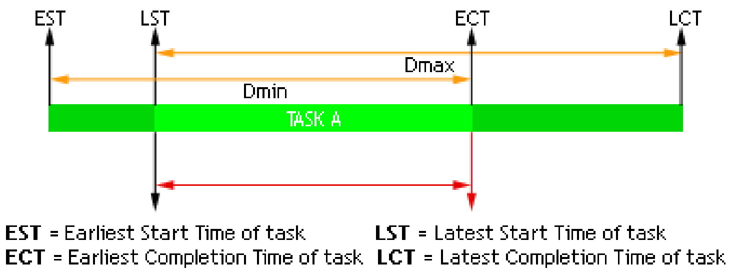
## setduration

### Purpose

A cptask is represented by three cpvar:

- 'start' representing the start time of the task
- 'end' representing the completion time of the task
- 'duration' representing the duration of the task.

These three structural variables are linked with the following constraint: task + duration $\leq$ end. The duration variable represents two specific parameters of the task: The minimum task duration (Dmin, represented by its lower bound) and the maximum task duration (Dmax, represented by its upper bound). The graphic below illustrates these properties:




### Synopsis

```
procedure setduration(task:cptask, duration:integer)
procedure setduration(task:cptask, durationMin:integer,
      durationMax:integer)
```

### Arguments

`task` a task

`duration` fixed duration of the task

`durationMin` minimum duration for the task

`durationMax` maximum duration for the task

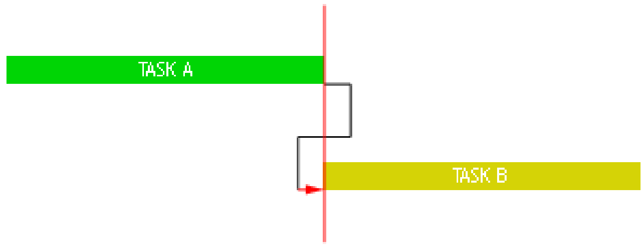
### Related topics

`getduration`

## addpredecessors

### Purpose

Adds a set of tasks as predecessors to a task. A task precedes some other task when it must be completed before the start of the second task. The following graphic shows two tasks A and B where A precedes B (and respectively B succeeds A as the relation is reflexive):




### Synopsis

```
procedure addpredecessors(task:cptask, predset:set of cptask)
```

### Arguments

`task` the task

`predset` the set of tasks that must precede 'task'

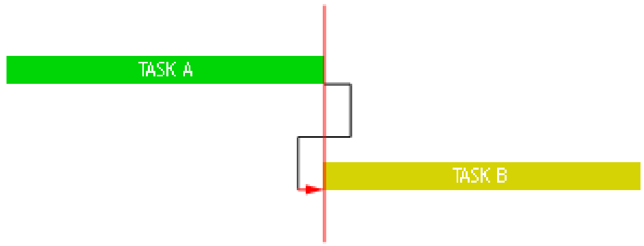
### Related topics

`addsucessors` `setpredecessors` `setsuccessors`

## setpredecessors

### Purpose

Sets the set of tasks that must precede a task. A task precedes some other task when it must be completed before the start of the second task. The following graphic shows two tasks A and B where A precedes B (and respectively B succedes A as the relation is reflexive):




### Synopsis

```
procedure setpredecessors(task:cptask, predset:set of cptask)
```

### Arguments

`task` the task

`predset` the set of tasks that must precede ‘task’

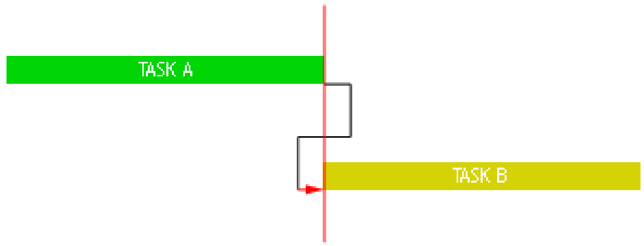
### Related topics

`addpredecessors` `addsucessors` `setsuccessors`

## addsuccessors

### Purpose

Adds a set of tasks as successor of a task. A task succeeds some other task when its processing cannot start before the completion of this task. The following graphic shows two tasks A and B where A precedes B (and respectively B succeeds to A as the relation is reflexive):




### Synopsis

```
procedure addsuccessors(task:cptask, succset:set of cptask)
```

### Arguments

`task` the task

`succset` the set of tasks that must succeed 'task'

### Related topics

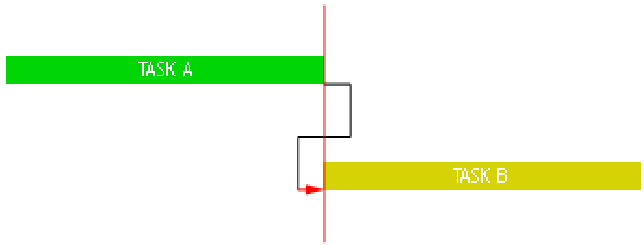
`addpredecessors` `setpredecessors` `setsuccessors`

## setsuccessors

### Purpose

Sets the set of tasks that must succeed a task. A task succeeds some other task when its processing cannot start before the completion of this task. The following schema shows two tasks A and B where A precedes B (and respectively B succeeds A as the relation is reflexive):




### Synopsis

```
procedure setsuccessors(task:cptask, succset:set of cptask)
```

### Arguments

`task` the task

`succset` the set of tasks that must succeed 'task'

### Related topics

`addpredecessors` `addsucessors` `setpredecessors`

# cp_show_schedule

**Purpose**

Shows a textual representation of the current schedule

**Synopsis**

```
procedure cp_show_schedule
```

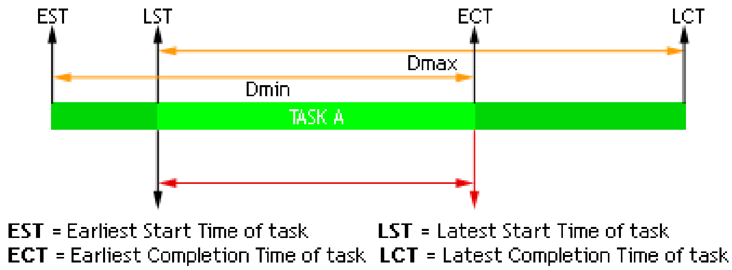
# getstart

### Purpose

A cptask is represented by three cpvar:

- 'start' representing the start time of the task
- 'end' representing the completion time of the task
- 'duration' representing the duration of the task.

These three structural variables are linked with the following constraint: start + duration $\leq$ end. The start time variable represents two specific parameters of the task: the Earliest Starting Time (EST represented by its lower bound) and its Latest Starting Time (LST represented by its upper bound). The graphic below illustrates these properties:




### Synopsis

```
function getstart(t:cptask) :  cpvar
```

### Argument

`t` the task

### Return value

The cpvar representing the start time of t

### Related topics

`getend` `getduration` `getconsumption` `getrequirement` `getproduction` `getprovision`

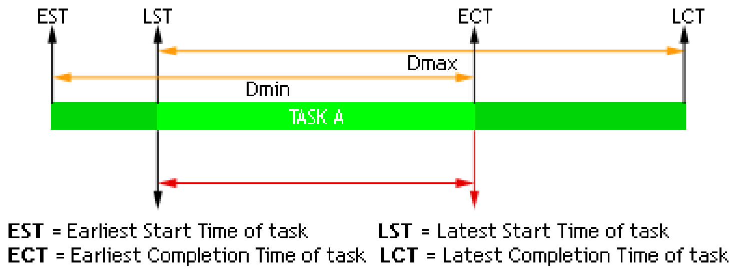
# getend

## Purpose

A cptask is represented by three cpvar:

- 'start' representing the start time of the task
- 'end' representing the completion time of the task
- 'duration' representing the duration of the task.

These three structural variables are linked with the following constraint: start + duration $\leq$ end. The end variable represents two specific parameters of the task: the Earliest Completion Time (ECT, represented by its lower bound) and its Latest Completion Time (LCT, represented by its upper bound). The graphic below illustrates these properties:




## Synopsis

```
function getend(t:cptask) :  cpvar
```

## Argument

`t` the task

## Return value

The cpvar representing the completion time of t

## Related topics

getstart getduration getconsumption getrequirement getproduction getprovision

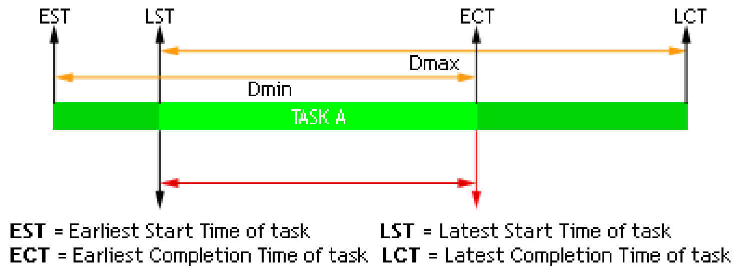
# getduration

### Purpose

A cptask is represented by three cpvar:

- 'start' representing the start time of the task
- 'end' representing the completion time of the task
- 'duration' representing the duration of the task.

These three structural variables are linked with the following constraint: start + duration $\leq$ end. The duration variable represents two specific parameters of the task: the minimum task duration (Dmin, represented by its lower bound) and the maximum task duration (Dmax represented by its upper bound). The graphic below illustrates these properties:




### Synopsis

```
function getduration(t:cptask) : cpvar
```

### Argument

`t` the task

### Return value

The cpvar representing the duration of t

### Related topics

`getstart getend getconsumption getrequirement getproduction getprovision`

## getconsumption

### Purpose

Gets the cpvar representing the consumption of a task for a particular resource.
A task consumes some amount of processing power of a resource when this amount must be made available for the execution of the task. The resource requirement is considered as renewable which means that whenever the task ends the processing power that was used is no longer available for processing other tasks.

### Synopsis

```
function getconsumption(task:cptask, resource:cpresource) :  cpvar
function getconsumption(task:cptask, resource:cpresource, p:integer) :
       integer
```

### Arguments

`task` the task

`resource` the resource

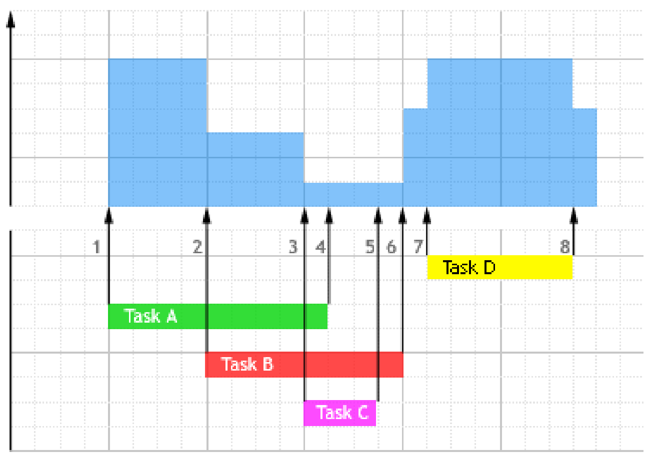
`p` the timestep

### Return value

The cpvar representing the consumption of 'resource' by 'task'

### Example

The following example illustrates this:




Task A produces 6 units of resource
Task B requires 3 units of resource
Task C consumes 2 units of resource
Task D provides 2 units of resource

1) Task A starts and produces 6 units of resource that will be available until the end of the schedule
2) Task B starts and requires 3 units of resource for it's execution. The resource availability is now 3 units less.
3) Task C starts and consumes 2 units of resource. The resource availability is lowered by two units until the end of the schedule.
4) Task A ends and the resource availability remains constant as the production is definitive.
5) Task C ends and the resource availability remains constant as the consumption of resource is definitive.
6) Task B ends and 3 units of resource are available again since resource requirement is recoverable.
7) Task D starts and provides 2 units of resource during it's execution.
8) Task D ends and the resource availabilty drop down of two units as the resource provision is recoverable.

```
model "Producer Consumer"
 uses "kalis"

 declarations
  Masonry, Carpentry, Roofing, Windows, Facade, Garden, Plumbing,
```

```
    Ceiling, Painting, MovingIn : cptask    ! Declaration of tasks
  money_available : cpresource              ! Resource declaration
 end-declarations

! 'money_available' is a cumulative resource with max. amount of 29$
 set_resource_attributes(money_available,KALIS_DISCRETE_RESOURCE,29)

! Limit resource availability to 20$ in the time interval [0,14]
 setcapacity(money_available, 0, 14, 20)

! Setting the task durations and predecessor sets
 set_task_attributes(Masonry   , 7 )
 set_task_attributes(Carpentry, 3, {Masonry} )
 set_task_attributes(Roofing   , 1, {Carpentry} )
 set_task_attributes(Windows   , 1, {Roofing} )
 set_task_attributes(Facade    , 2, {Roofing} )
 set_task_attributes(Garden    , 1, {Roofing} )
 set_task_attributes(Plumbing , 8, {Masonry} )
 set_task_attributes(Ceiling   , 3, {Masonry} )
 set_task_attributes(Painting , 2, {Ceiling} )
 set_task_attributes(MovingIn , 1, {Windows,Facade,Garden,Painting})

! Setting the resource consumptions
 consumes(Masonry   , 7, money_available )
 consumes(Carpentry, 3, money_available )
 consumes(Roofing   , 1, money_available )
 consumes(Windows   , 1, money_available )
 consumes(Facade    , 2, money_available )
 consumes(Garden    , 1, money_available )
 consumes(Plumbing , 8, money_available )
 consumes(Ceiling   , 3, money_available )
 consumes(Painting , 2, money_available )
 consumes(MovingIn , 1, money_available )

! Find the optimal schedule (minimizing the makespan)
 if cp_minimize(getmakespan) then
   cp_show_sol
 else
   writeln("No solution found")
 end-if

end-model
```

## Related topics

getstart getend getduration getrequirement getproduction getprovision

## getrequirement

### Purpose

Gets the cpvar representing the requirement of a task for a particular resource.
A task requires some amount of processing power of a resource when this amount must be made available for the execution of the task. The resource requirement is considered as recoverable which means that whenever the task ends the processing power that was used by it becomes available again for processing other tasks.

### Synopsis

```
function getrequirement(task:cptask, resource:cpresource) :  cpvar
function getrequirement(task:cptask, resource:cpresource, p:integer) :
      integer
```

### Arguments

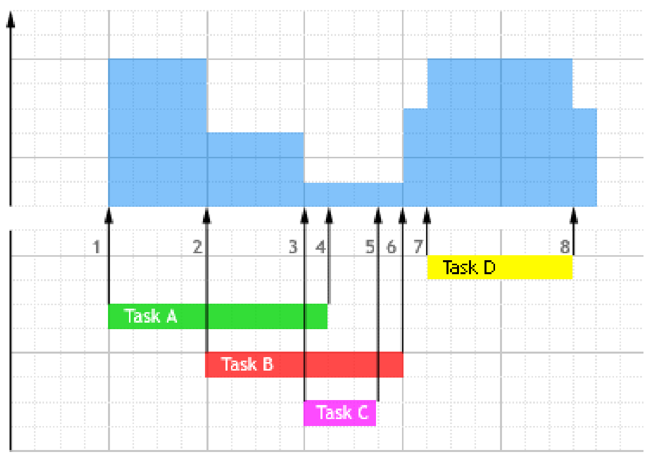
| | |
|---|---|
| `task` | the task |
| `resource` | the resource |
| `p` | the timestep |

### Return value

The cpvar representing the requirement of 'resource' by 'task'

### Example

The following example illustrates this:




Task A produces 6 units of resource
Task B requires 3 units of resource
Task C consumes 2 units of resource
Task D provides 2 units of resource

1) Task A starts and produces 6 units of resource that will be available until the end of the schedule
2) Task B starts and requires 3 units of resource for it's execution. The resource availability is now 3 units less.
3) Task C starts and consumes 2 units of resource. The resource availability is lowered by two units until the end of the schedule.
4) Task A ends and the resource availability remains constant as the production is definitive.
5) Task C ends and the resource availability remains constant as the consumption of resource is definitive.
6) Task B ends and 3 units of resource are available again since resource requirement is recoverable.
7) Task D starts and provides 2 units of resource during it's execution.
8) Task D ends and the resource availabilty drop down of two units as the resource provision is recoverable.

```
model "Producer Consumer"
 uses "kalis"

 declarations
  Masonry, Carpentry, Roofing, Windows, Facade, Garden, Plumbing,
```

```
    Ceiling, Painting, MovingIn : cptask     ! Declaration of tasks
  money_available : cpresource               ! Resource declaration
 end-declarations

! 'money_available' is a cumulative resource with max. amount of 29$
 set_resource_attributes(money_available,KALIS_DISCRETE_RESOURCE,29)

! Limit resource availability to 20$ in the time interval [0,14]
 setcapacity(money_available, 0, 14, 20)

! Setting the task durations and predecessor sets
 set_task_attributes(Masonry   , 7 )
 set_task_attributes(Carpentry, 3, {Masonry} )
 set_task_attributes(Roofing   , 1, {Carpentry} )
 set_task_attributes(Windows   , 1, {Roofing} )
 set_task_attributes(Facade    , 2, {Roofing} )
 set_task_attributes(Garden    , 1, {Roofing} )
 set_task_attributes(Plumbing , 8, {Masonry} )
 set_task_attributes(Ceiling   , 3, {Masonry} )
 set_task_attributes(Painting , 2, {Ceiling} )
 set_task_attributes(MovingIn , 1, {Windows,Facade,Garden,Painting})

! Setting the resource consumptions
 consumes(Masonry   , 7, money_available )
 consumes(Carpentry, 3, money_available )
 consumes(Roofing   , 1, money_available )
 consumes(Windows   , 1, money_available )
 consumes(Facade    , 2, money_available )
 consumes(Garden    , 1, money_available )
 consumes(Plumbing , 8, money_available )
 consumes(Ceiling   , 3, money_available )
 consumes(Painting , 2, money_available )
 consumes(MovingIn , 1, money_available )

! Find the optimal schedule (minimizing the makespan)
 if cp_minimize(getmakespan) then
   cp_show_sol
 else
   writeln("No solution found")
 end-if

end-model
```

### Related topics

getstart getend getduration getconsumption getproduction getprovision

# getproduction

## Purpose

Gets the cpvar representing the production of a task for a particular resource.
A task produces some amount of processing power for a resource at its start. The capacity produced is considered as non-renewable which means that the produced capacity remains available even after the termination of the task.

## Synopsis

```
function getproduction(task:cptask, resource:cpresource) :  cpvar
function getproduction(task:cptask, resource:cpresource, p:integer) :
       integer
```

## Arguments

`task` the task

`resource` the resource

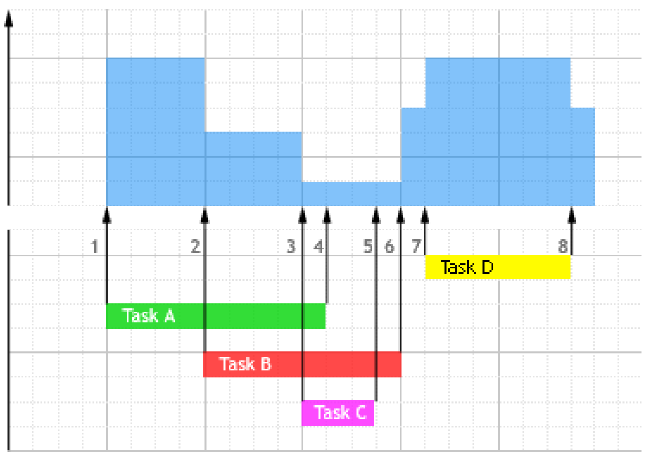
`p` the timestep

## Return value

The cpvar representing the production of 'resource' by 'task'

## Example

The following example illustrates this:




Task A produces 6 units of resource
Task B requires 3 units of resource
Task C consumes 2 units of resource
Task D provides 2 units of resource

1) Task A starts and produces 6 units of resource that will be available until the end of the schedule
2) Task B starts and requires 3 units of resource for it's execution. The resource availability is now 3 units less.
3) Task C starts and consumes 2 units of resource. The resource availability is lowered by two units until the end of the schedule.
4) Task A ends and the resource availability remains constant as the production is definitive.
5) Task C ends and the resource availability remains constant as the consumption of resource is definitive.
6) Task B ends and 3 units of resource are available again since resource requirement is recoverable.
7) Task D starts and provides 2 units of resource during it's execution.
8) Task D ends and the resource availabilty drop down of two units as the resource provision is recoverable.

```
model "Producer Consumer"
 uses "kalis"

 declarations
  Masonry, Carpentry, Roofing, Windows, Facade, Garden, Plumbing,
    Ceiling, Painting, MovingIn : cptask     ! Declaration of tasks
```

```
  money_available : cpresource              ! Resource declaration
 end-declarations

! 'money_available' is a cumulative resource with max. amount of 29$
 set_resource_attributes(money_available,KALIS_DISCRETE_RESOURCE,29)

! Limit resource availability to 20$ in the time interval [0,14]
 setcapacity(money_available, 0, 14, 20)

! Setting the task durations and predecessor sets
 set_task_attributes(Masonry  , 7 )
 set_task_attributes(Carpentry, 3, {Masonry} )
 set_task_attributes(Roofing  , 1, {Carpentry} )
 set_task_attributes(Windows  , 1, {Roofing} )
 set_task_attributes(Facade   , 2, {Roofing} )
 set_task_attributes(Garden   , 1, {Roofing} )
 set_task_attributes(Plumbing , 8, {Masonry} )
 set_task_attributes(Ceiling  , 3, {Masonry} )
 set_task_attributes(Painting , 2, {Ceiling} )
 set_task_attributes(MovingIn , 1, {Windows,Facade,Garden,Painting})

! Setting the resource consumptions
 consumes(Masonry  , 7, money_available )
 consumes(Carpentry, 3, money_available )
 consumes(Roofing  , 1, money_available )
 consumes(Windows  , 1, money_available )
 consumes(Facade   , 2, money_available )
 consumes(Garden   , 1, money_available )
 consumes(Plumbing , 8, money_available )
 consumes(Ceiling  , 3, money_available )
 consumes(Painting , 2, money_available )
 consumes(MovingIn , 1, money_available )

! Find the optimal schedule (minimizing the makespan)
 if cp_minimize(getmakespan) then
   cp_show_sol
 else
   writeln("No solution found")
 end-if

end-model
```

### Related topics

getstart getend getduration getconsumption getrequirement getprovision

## getprovision

### Purpose

Gets the cpvar representing the provision of a task for a particular resource.
A task provides some amount of processing power for a resource during its execution. The capacity provided is considered as renewable which means that whenever the providing task ends, the provided capacity is no longer available.

### Synopsis

```
function getprovision(task:cptask, resource:cpresource) :  cpvar
function getprovision(task:cptask, resource:cpresource, p:integer) :
       integer
```

### Arguments

`task` the task

`resource` the resource

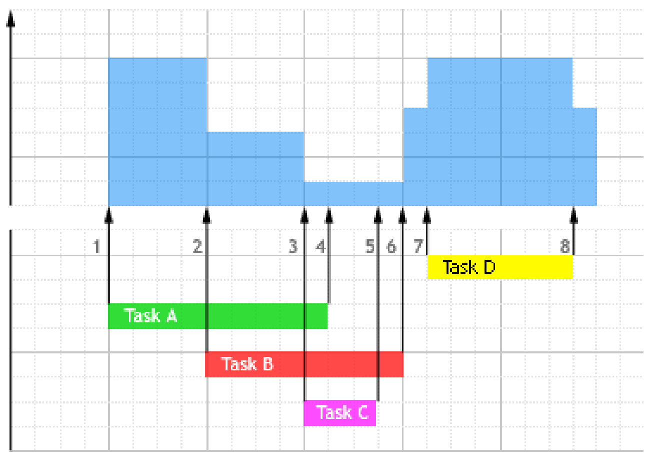
`p` the timestep

### Return value

The cpvar representing the provision of 'resource' by 'task'

### Example

The following example illustrates this:




Task A produces 6 units of resource
Task B requires 3 units of resource
Task C consumes 2 units of resource
Task D provides 2 units of resource

1) Task A starts and produces 6 units of resource that will be available until the end of the schedule
2) Task B starts and requires 3 units of resource for it's execution. The resource availability is now 3 units less.
3) Task C starts and consumes 2 units of resource. The resource availability is lowered by two units until the end of the schedule.
4) Task A ends and the resource availability remains constant as the production is definitive.
5) Task C ends and the resource availability remains constant as the consumption of resource is definitive.
6) Task B ends and 3 units of resource are available again since resource requirement is recoverable.
7) Task D starts and provides 2 units of resource during it's execution.
8) Task D ends and the resource availabilty drop down of two units as the resource provision is recoverable.

```
model "Producer Consumer"
 uses "kalis"

 declarations
  Masonry, Carpentry, Roofing, Windows, Facade, Garden, Plumbing,
    Ceiling, Painting, MovingIn : cptask     ! Declaration of tasks
```

```
  money_available : cpresource              ! Resource declaration
 end-declarations

! 'money_available' is a cumulative resource with max. amount of 29$
 set_resource_attributes(money_available,KALIS_DISCRETE_RESOURCE,29)

! Limit resource availability to 20$ in the time interval [0,14]
 setcapacity(money_available, 0, 14, 20)

! Setting the task durations and predecessor sets
 set_task_attributes(Masonry  , 7 )
 set_task_attributes(Carpentry, 3, {Masonry} )
 set_task_attributes(Roofing  , 1, {Carpentry} )
 set_task_attributes(Windows  , 1, {Roofing} )
 set_task_attributes(Facade   , 2, {Roofing} )
 set_task_attributes(Garden   , 1, {Roofing} )
 set_task_attributes(Plumbing , 8, {Masonry} )
 set_task_attributes(Ceiling  , 3, {Masonry} )
 set_task_attributes(Painting , 2, {Ceiling} )
 set_task_attributes(MovingIn , 1, {Windows,Facade,Garden,Painting})

! Setting the resource consumptions
 consumes(Masonry  , 7, money_available )
 consumes(Carpentry, 3, money_available )
 consumes(Roofing  , 1, money_available )
 consumes(Windows  , 1, money_available )
 consumes(Facade   , 2, money_available )
 consumes(Garden   , 1, money_available )
 consumes(Plumbing , 8, money_available )
 consumes(Ceiling  , 3, money_available )
 consumes(Painting , 2, money_available )
 consumes(MovingIn , 1, money_available )

! Find the optimal schedule (minimizing the makespan)
 if cp_minimize(getmakespan) then
   cp_show_sol
 else
   writeln("No solution found")
 end-if

end-model
```

## Related topics

getstart getend getduration getconsumption getrequirement getproduction

## is_consuming

### Purpose

Returns true IFF the specified task consumes a specific resource

### Synopsis

```
function is_consuming(task:cptask, resource:cpresource) :  boolean
```

### Arguments

`task` the task

`resource` the resource

### Return value

`true` IFF the task consumes the specified resource, `false` otherwise

### Related topics

`is_requiring` `is_producing` `is_providing`

## is_requiring

### Purpose

Returns true IFF the specified task requires a specific resource

### Synopsis

```
function is_requiring(task:cptask, resource:cpresource) :  boolean
```

### Arguments

`task` the task

`resource` the resource

### Return value

`true` IFF the task requires the specified resource, `false` otherwise

### Related topics

`is_consuming` `is_producing` `is_providing`

## is_producing

### Purpose

Returns true IFF the specified task produces a specific resource

### Synopsis

```
function is_producing(task:cptask, resource:cpresource) :  boolean
```

### Arguments

`task` the task

`resource` the resource

### Return value

`true` IFF the task produces the specified resource, `false` otherwise

### Related topics

`is_consuming` `is_requiring` `is_providing`

# is_providing

### Purpose

Returns true IFF the specified task provides a specific resource

### Synopsis

```
function is_providing(task:cptask, resource:cpresource) :  boolean
```

### Arguments

`task` the task

`resource` the resource

### Return value

`true` IFF the task provides the specified resource, `false` otherwise

### Related topics

`is_consuming` `is_requiring` `is_producing`

## cp_schedule

### Purpose

Optimizes the schedule with respect to an objective variable.

### Synopsis

```
function cp_schedule(obj:cpvar) : integer
function cp_schedule(obj:cpfloatvar) : integer
function cp_schedule(obj:cpfloatvar, maximization:boolean) : integer
function cp_schedule(obj:cpvar, maximization:boolean) : integer
```

### Arguments

`obj` the objective variable

`maximization` `true` for maximization of the objective and `false` for minimization (default: minimization)

### Return value

0 if schedule is inconsistent, 1 if schedule is suboptimal, 2 if schedule is optimal

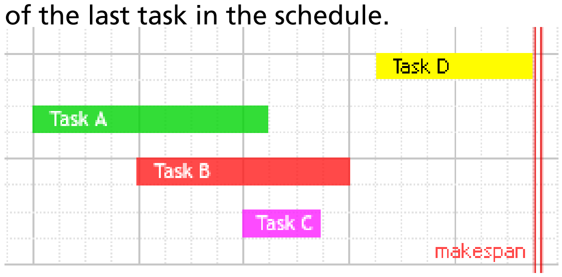
### Related topics

`getmakespan` `cp_set_schedule_strategy`

# getmakespan

### Purpose

Gets the cpvar representing the makespan of the schedule. The makespan is the completion time of the last task in the schedule.




### Synopsis

```
function getmakespan :  cpvar
```

### Return value

The cpvar representing the makespan of the schedule

### Related topics

`cp_schedule`

## consumes

### Purpose

Sets the minimal and maximal amount of resource consumed by a task for a particular resource. A task consumes some amount of processing power of a resource when this amount must be made available for the execution of the task. The resource requirement is considered as renewable which means that whenever the tasks ends The processing power that was required is no longer available for processing other tasks. Note that a minimal amount of 0 is possible thus allowing modeling of alternative resources. The type of resource consumption can be defined in several ways:

- By specifying a resource and a constant consumption parameter *'consumption'*. In this case the resource consumption is constant other the execution of the task.
- By specifying a resource and a minimal *'minCons'* and maximal *'maxCons'* consumption parameters: In this case the resource consumption is a decision variable but is constant other the execution of the task.
- By specifying a cpresusage *'usage'* (see `resusage` for further detail).
- By a set of alternative cpresusage *'optUsages'*: This makes it possible to model alternative resources. The type of resource consumption is defined by the resource usage passed in argument (see `resusage` for further detail).
- By a set of alternative cpresusage *'optUsages'* , a minimal *'minalt'* and a maximal *'maxalt'* number of alternative resources that must be consumed: Between [minalt..maxalt] alternative consumptions from the set defined will be active which means that several resources will be chosen to be consumed by the task. The type of resource consumption is defined by the resource usage passed in argument (see `resusage` for further detail).

### Synopsis

```
procedure consumes(task:cptask, consumption:integer, resource:cpresource)
procedure consumes(task:cptask, consumptionMin:integer, consumptionMax,
       resource:cpresource)
procedure consumes(task:cptask, usage:cpresusage)
procedure consumes(task:cptask, optUsages:set of cpresusage)
procedure consumes(task:cptask, optUsages:set of cpresusage,
       minalt:integer, maxalt:integer)
```

### Arguments

`task` the task

`consumption` constant positive resource consumption

`minCons` minimal resource consumption

`maxCons` maximal resource consumption

`resource` the resource to be consumed

`usage` the resource usage

`optUsages` the set of alternatives resource consumption

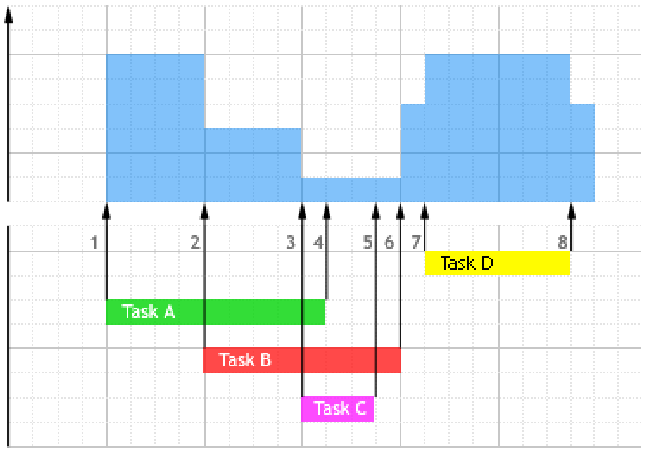
`minalt` minimal number of resources that must be consumed

`maxalt` maximal number of resources that may be consumed

### Example

The following example illustrates this:




Task A produces 6 units of resource
Task B requires 3 units of resource
Task C consumes 2 units of resource
Task D provides 2 units of resource

1) Task A starts and produces 6 units of resource that will be available until the end of the schedule
2) Task B starts and requires 3 units of resource for it's execution. The resource availability is now 3 units less.
3) Task C starts and consumes 2 units of resource. The resource availability is lowered by two units until the end of the schedule.
4) Task A ends and the resource availability remains constant as the production is definitive.
5) Task C ends and the resource availability remains constant as the consumption of resource is definitive.
6) Task B ends and 3 units of resource are available again since resource requirement is recoverable.
7) Task D starts and provides 2 units of resource during it's execution.
8) Task D ends and the resource availabilty drop down of two units as the resource provision is recoverable.

```
model "Producer Consumer"
 uses "kalis"

 declarations
  Masonry, Carpentry, Roofing, Windows, Facade, Garden, Plumbing,
    Ceiling, Painting, MovingIn : cptask     ! Declaration of tasks
  money_available : cpresource               ! Resource declaration
 end-declarations

! 'money_available' is a cumulative resource with max. amount of 29$
 set_resource_attributes(money_available,KALIS_DISCRETE_RESOURCE,29)

! Limit resource availability to 20$ in the time interval [0,14]
 setcapacity(money_available, 0, 14, 20)

! Setting the task durations and predecessor sets
 set_task_attributes(Masonry   , 7 )
 set_task_attributes(Carpentry, 3, {Masonry} )
 set_task_attributes(Roofing   , 1, {Carpentry} )
 set_task_attributes(Windows   , 1, {Roofing} )
 set_task_attributes(Facade    , 2, {Roofing} )
 set_task_attributes(Garden    , 1, {Roofing} )
 set_task_attributes(Plumbing , 8, {Masonry} )
 set_task_attributes(Ceiling   , 3, {Masonry} )
 set_task_attributes(Painting , 2, {Ceiling} )
 set_task_attributes(MovingIn , 1, {Windows,Facade,Garden,Painting})

! Setting the resource consumptions
 consumes(Masonry  , 7, money_available )
```

```
 consumes(Carpentry, 3, money_available )
 consumes(Roofing  , 1, money_available )
 consumes(Windows  , 1, money_available )
 consumes(Facade   , 2, money_available )
 consumes(Garden   , 1, money_available )
 consumes(Plumbing , 8, money_available )
 consumes(Ceiling  , 3, money_available )
 consumes(Painting , 2, money_available )
 consumes(MovingIn , 1, money_available )

! Find the optimal schedule (minimizing the makespan)
 if cp_minimize(getmakespan) then
   cp_show_sol
 else
   writeln("No solution found")
 end-if

end-model
```

## Related topics

produces provides requires is_providing is_consuming is_requiring is_producing resusage

## requires

### Purpose

Sets the minimal and maximal amount of resource required by a task for a particular resource. A task requires some amount of processing power of a resource when this amount must be made available for the execution of the task. The resource requirement is considered as renewable which means that whenever the tasks ends the processing power that was required is still available for processing other tasks. Note that a minimal amount of 0 is possible thus allowing modelisation of alternative resources. The type of resource requirement can be defined in several ways:

- By specifying a resource and a constant requirement parameter *'requirement'*. In this case the resource requirement is constant other the execution of the task.
- By specifying a resource and a minimal *'minReq'* and maximal *'maxReq'* requirement parameters: In this case the resource requirement is a decision variable but is constant other the execution of the task.
- By specifying a cpresusage *'usage'* (see `resusage` for further detail).
- By a set of alternative cpresusage *'optUsages'*: This makes it possible to model alternative resources. The type of resource requirement is defined by the resource usage passed in argument (see `resusage` for further detail).
- By a set of alternative cpresusage *'optUsages'*, a minimal *'minalt'* and a maximal *'maxalt'* number of alternative resources that are required: Between [minalt..maxalt] alternative requirements from the set will be active which means that several resources will be chosen as requirements by the task. The type of resource requirement is defined by the resource usage passed in argument (see `resusage` for further detail).

### Synopsis

```
procedure requires(task:cptask, requirement:integer, resource:cpresource)
procedure requires(task:cptask, minReq:integer, maxReq:integer,
       resource:cpresource)
procedure requires(task:cptask, usage:cpresusage)
procedure requires(task:cptask, optUsages:set of cpresusage)
procedure requires(task:cptask, optUsages:set of cpresusage,
       minalt:integer, maxalt:integer)
```

### Arguments

`task` the task

`requirement` constant positive resource consumption

`minReq` minimal resource requirement

`maxReq` maximal resource requirement

`resource` the resource to be required

`usage` the resource usage

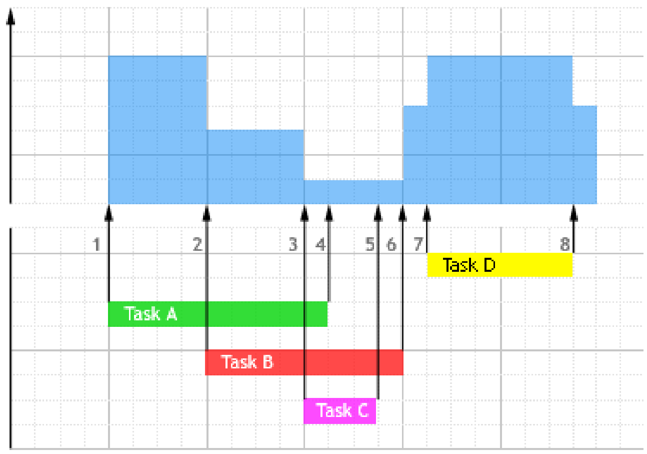
`optUsages` the set of alternatives resource requirements

`minalt` minimal number of resources that must be required

`maxalt` maximal number of resources that may be required

### Example

The following example illustrates this:




Task A produces 6 units of resource
Task B requires 3 units of resource
Task C consumes 2 units of resource
Task D provides 2 units of resource

1) Task A starts and produces 6 units of resource that will be available until the end of the schedule
2) Task B starts and requires 3 units of resource for it's execution. The resource availability is now 3 units less.
3) Task C starts and consumes 2 units of resource. The resource availability is lowered by two units until the end of the schedule.
4) Task A ends and the resource availability remains constant as the production is definitive.
5) Task C ends and the resource availability remains constant as the consumption of resource is definitive.
6) Task B ends and 3 units of resource are available again since resource requirement is recoverable.
7) Task D starts and provides 2 units of resource during it's execution.
8) Task D ends and the resource availabilty drop down of two units as the resource provision is recoverable.

```
model "Producer Consumer"
 uses "kalis"

 declarations
  Masonry, Carpentry, Roofing, Windows, Facade, Garden, Plumbing,
    Ceiling, Painting, MovingIn : cptask     ! Declaration of tasks
  money_available : cpresource               ! Resource declaration
 end-declarations

! 'money_available' is a cumulative resource with max. amount of 29$
 set_resource_attributes(money_available,KALIS_DISCRETE_RESOURCE,29)

! Limit resource availability to 20$ in the time interval [0,14]
 setcapacity(money_available, 0, 14, 20)

! Setting the task durations and predecessor sets
 set_task_attributes(Masonry   , 7 )
 set_task_attributes(Carpentry, 3, {Masonry} )
 set_task_attributes(Roofing   , 1, {Carpentry} )
 set_task_attributes(Windows   , 1, {Roofing} )
 set_task_attributes(Facade    , 2, {Roofing} )
 set_task_attributes(Garden    , 1, {Roofing} )
 set_task_attributes(Plumbing , 8, {Masonry} )
 set_task_attributes(Ceiling   , 3, {Masonry} )
 set_task_attributes(Painting , 2, {Ceiling} )
 set_task_attributes(MovingIn , 1, {Windows,Facade,Garden,Painting})

! Setting the resource consumptions
 consumes(Masonry  , 7, money_available )
```

```
 consumes(Carpentry, 3, money_available )
 consumes(Roofing  , 1, money_available )
 consumes(Windows  , 1, money_available )
 consumes(Facade   , 2, money_available )
 consumes(Garden   , 1, money_available )
 consumes(Plumbing , 8, money_available )
 consumes(Ceiling  , 3, money_available )
 consumes(Painting , 2, money_available )
 consumes(MovingIn , 1, money_available )

! Find the optimal schedule (minimizing the makespan)
 if cp_minimize(getmakespan) then
   cp_show_sol
 else
   writeln("No solution found")
 end-if

end-model
```

### Related topics

produces provides requires is_providing is_consuming is_requiring is_producing resusage

## produces

### Purpose

Sets the minimal and maximal amount of resource produced by a task for a particular resource. A task produces some amount of processing power for a resource at its start. The capacity produced is considered as non renewable which means that the produced capacity remains available even after the completion of the task. Note that a minimal amount of 0 is possible thus allowing modelisation of alternative resources. The type of resource production can be defined in several ways:

- By specifying a resource and a constant production parameter *'production'*. In this case the resource production is constant other the execution of the task.
- By specifying a resource and a minimal *'minProd'* and maximal *'maxProd'* production parameters: In this case the resource production is a decision variable but is constant over the execution of the task.
- By specifying a cpresusage *'usage'* (see `resusage` for further detail).
- By a set of alternative cpresusage *'optUsages'*: This makes it possible to model alternative resources. The type of resource production is defined by the resource usage passed in argument (see `resusage` for further detail).
- By a set of alternative cpresusage *'optUsages'*, a minimal *'minalt'* and a maximal *'maxalt'* number of alternative resources that may be produced: Between [minalt..maxalt] alternative productions from the set will be active which means that several resources will be chosen to be produced by the task. The type of resource production is defined by the resource usage passed in argument (see `resusage` for further detail)

### Synopsis

```
procedure produces(task:cptask, production:integer, resource:cpresource)
procedure produces(task:cptask,minProd:integer, maxProd:integer,
      resource:cpresource)
procedure produces(task:cptask, usage:cpresusage)
procedure produces(task:cptask, optUsages:set of cpresusage)
procedure produces(task:cptask, optUsages:set of cpresusage,
      minalt:integer, maxalt:integer)
```

### Arguments

`task` the task

`production` constant positive resource production

`minProd` minimal resource production

`maxProd` maximal resource production

`resource` the resource to be produced

`usage` the resource usage

`optUsages` the set of alternatives resource production

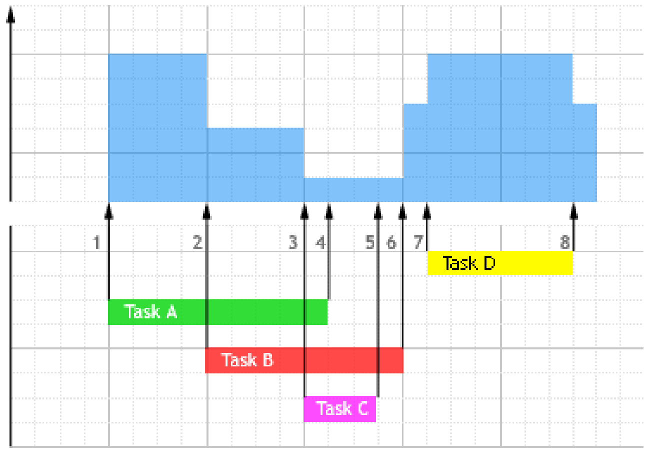
`minalt` minimal number of resources that must be produced

`maxalt` maximal number of resources that may be produced

### Example

The following example illustrates this:




Task A produces 6 units of resource
Task B requires 3 units of resource
Task C consumes 2 units of resource
Task D provides 2 units of resource

1) Task A starts and produces 6 units of resource that will be available until the end of the schedule
2) Task B starts and requires 3 units of resource for it's execution. The resource availability is now 3 units less.
3) Task C starts and consumes 2 units of resource. The resource availability is lowered by two units until the end of the schedule.
4) Task A ends and the resource availability remains constant as the production is definitive.
5) Task C ends and the resource availability remains constant as the consumption of resource is definitive.
6) Task B ends and 3 units of resource are available again since resource requirement is recoverable.
7) Task D starts and provides 2 units of resource during it's execution.
8) Task D ends and the resource availabilty drop down of two units as the resource provision is recoverable.

```
model "Producer Consumer"
 uses "kalis"

 declarations
  Masonry, Carpentry, Roofing, Windows, Facade, Garden, Plumbing,
    Ceiling, Painting, MovingIn : cptask     ! Declaration of tasks
  money_available : cpresource               ! Resource declaration
 end-declarations

! 'money_available' is a cumulative resource with max. amount of 29$
 set_resource_attributes(money_available,KALIS_DISCRETE_RESOURCE,29)

! Limit resource availability to 20$ in the time interval [0,14]
 setcapacity(money_available, 0, 14, 20)

! Setting the task durations and predecessor sets
 set_task_attributes(Masonry   , 7 )
 set_task_attributes(Carpentry, 3, {Masonry} )
 set_task_attributes(Roofing   , 1, {Carpentry} )
 set_task_attributes(Windows   , 1, {Roofing} )
 set_task_attributes(Facade    , 2, {Roofing} )
 set_task_attributes(Garden    , 1, {Roofing} )
 set_task_attributes(Plumbing , 8, {Masonry} )
 set_task_attributes(Ceiling   , 3, {Masonry} )
 set_task_attributes(Painting , 2, {Ceiling} )
 set_task_attributes(MovingIn , 1, {Windows,Facade,Garden,Painting})

! Setting the resource consumptions
 consumes(Masonry  , 7, money_available )
```

```
 consumes(Carpentry, 3, money_available )
 consumes(Roofing  , 1, money_available )
 consumes(Windows  , 1, money_available )
 consumes(Facade   , 2, money_available )
 consumes(Garden   , 1, money_available )
 consumes(Plumbing , 8, money_available )
 consumes(Ceiling  , 3, money_available )
 consumes(Painting , 2, money_available )
 consumes(MovingIn , 1, money_available )

! Find the optimal schedule (minimizing the makespan)
 if cp_minimize(getmakespan) then
   cp_show_sol
 else
   writeln("No solution found")
 end-if

end-model
```

### Related topics

produces provides requires is_providing is_consuming is_requiring is_producing resusage

## provides

### Purpose

Sets the minimal and maximal amount of resource provided by a task for a particular resource. A task provides some amount of processing power for a resource during its execution. The capacity provided is considered as renewable which means that whenever the providing task ends, the provided capacity is no longer available. Note that a minimal amount of 0 is possible thus allowing modeling of alternative resources. The type of resource provision can be defined in several ways:

- By specifying a resource and a constant provision parameter *'provision'*. In this case the resource provision is constant over the execution of the task.
- By specifying a resource and minimal *'minProv'* and maximal *'maxProv'* provision parameters: In this case the resource provision is a decision variable but is constant over the execution of the task.
- By specifying a cpresusage *'usage'* (see `resusage` for further detail).
- By a set of alternative cpresusage *'optUsages'*: This makes it possible to model alternative resources. The type of resource provision is defined by the resource usage passed in argument (see `resusage` for further detail).
- By a set of alternative cpresusage *'optUsages'*, a minimal *'minalt'* and a maximal *'maxalt'* number of alternative resources that must be provided: Between [minalt..maxalt] alternative provisions from the set will be active which means that several resources will be chosen to be provided by the task. The type of resource provision is defined by the resource usage passed in argument (see `resusage` for further detail).

### Synopsis

```
procedure provides(task:cptask, provision:integer, resource:cpresource)
procedure provides(task:cptask, minProv:integer, maxProv:integer,
       resource:cpresource)
procedure provides(task:cptask, usage:cpresusage)
procedure provides(task:cptask, optUsages:set of cpresusage)
procedure provides(task:cptask, optUsages:set of cpresusage,
       minalt:integer, maxalt:integer)
```

### Arguments

`task` the task

`provision` constant positive resource consumption

`minProv` minimal resource consumption

`maxProv` maximal resource provision

`resource` the resource to be provided

`usage` the resource usage

`optUsages` the set of alternatives resource provision

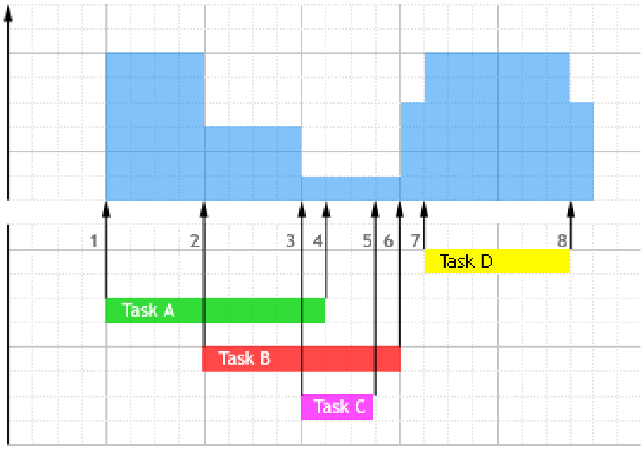
`minalt` minimal number of resources that must be provided

`maxalt` maximal number of resources that may be provided

### Example

The following example illustrates this:




Task A produces 6 units of resource
Task B requires 3 units of resource
Task C consumes 2 units of resource
Task D provides 2 units of resource

1) Task A starts and produces 6 units of resource that will be available until the end of the schedule
2) Task B starts and requires 3 units of resource for it's execution. The resource availability is now 3 units less.
3) Task C starts and consumes 2 units of resource. The resource availability is lowered by two units until the end of the schedule.
4) Task A ends and the resource availability remains constant as the production is definitive.
5) Task C ends and the resource availability remains constant as the consumption of resource is definitive.
6) Task B ends and 3 units of resource are available again since resource requirement is recoverable.
7) Task D starts and provides 2 units of resource during it's execution.
8) Task D ends and the resource availabilty drop down of two units as the resource provision is recoverable.

```
model "Producer Consumer"
 uses "kalis"

 declarations
  Masonry, Carpentry, Roofing, Windows, Facade, Garden, Plumbing,
    Ceiling, Painting, MovingIn : cptask     ! Declaration of tasks
  money_available : cpresource               ! Resource declaration
 end-declarations

! 'money_available' is a cumulative resource with max. amount of 29$
 set_resource_attributes(money_available,KALIS_DISCRETE_RESOURCE,29)

! Limit resource availability to 20$ in the time interval [0,14]
 setcapacity(money_available, 0, 14, 20)

! Setting the task durations and predecessor sets
 set_task_attributes(Masonry   , 7 )
 set_task_attributes(Carpentry, 3, {Masonry} )
 set_task_attributes(Roofing   , 1, {Carpentry} )
 set_task_attributes(Windows   , 1, {Roofing} )
 set_task_attributes(Facade    , 2, {Roofing} )
 set_task_attributes(Garden    , 1, {Roofing} )
 set_task_attributes(Plumbing  , 8, {Masonry} )
 set_task_attributes(Ceiling   , 3, {Masonry} )
 set_task_attributes(Painting  , 2, {Ceiling} )
 set_task_attributes(MovingIn  , 1, {Windows,Facade,Garden,Painting})

! Setting the resource consumptions
 consumes(Masonry  , 7, money_available )
```

```
 consumes(Carpentry, 3, money_available )
 consumes(Roofing  , 1, money_available )
 consumes(Windows  , 1, money_available )
 consumes(Facade   , 2, money_available )
 consumes(Garden   , 1, money_available )
 consumes(Plumbing , 8, money_available )
 consumes(Ceiling  , 3, money_available )
 consumes(Painting , 2, money_available )
 consumes(MovingIn , 1, money_available )

! Find the optimal schedule (minimizing the makespan)
 if cp_minimize(getmakespan) then
   cp_show_sol
 else
   writeln("No solution found")
 end-if

end-model
```

### Related topics

produces provides requires is_providing is_consuming is_requiring is_producing resusage

## set_resource_attributes

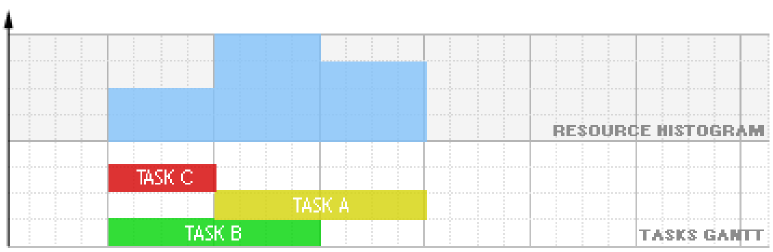
### Purpose

Sets some attributes for a resource.
A resource can be of two different types:

- *Disjunctive* when the resource can be used only by one task at a time.
- *Cumulative* when the resource can be used by several tasks at the same time.

Note that a disjunctive resource is semantically equivalent to a cumulative resource with maximal capacity one and unit resource usage for each task using this resource but this equivalence does not hold in terms of constraint propagation. The parameter type allows the user to choose between a disjunctive resource (KALIS_UNARY_RESOURCE) and a cumulative resource (KALIS_DISCRETE_RESOURCE). The last parameter, capacity, indicates the structural maximal capacity of the resource. When the resource is disjunctive this parameter must be equal to one. The structural capacity does not vary over time but a maximal temporal capacity can be imposed at any time point with the `setcapacity` function. The following graphic shows an example with three tasks A, B and C processed on a disjunctive resource and on a cumulative resource with resource usage 3 for task A, 1 for task B and 1 for task C.


DISJUNCTIVE RESOURCE




CUMULATIVE RESOURCE

### Synopsis

```
procedure set_resource_attributes(resource:cpresource, type:integer)
procedure set_resource_attributes(resource:cpresource, type:integer,
       capacity:integer)
procedure set_resource_attributes(resource:cpresource, type:integer,
       capacity:integer, propagationHint:integer)
```

### Arguments

`resource` the resource

`type` resource type: `KALIS_DISCRETE_RESOURCE` or `KALIS_UNARY_RESOURCE`

`capacity` maximal capacity of the resource

`alg` propagation algorithm choice: `KALIS_TIMETABLING`, `KALIS_TASK_INTERVALS`, or `KALIS_DISJUNCTIONS`

### Related topics

`set_task_attributes`

## setcapacity

### Purpose

Sets the maximal capacity (the maximal amount of processing units available) of a resource between two time bounds.

### Synopsis

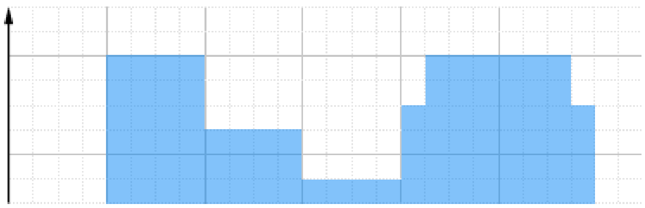
```
procedure setcapacity(resource:cpresource, tmin:integer, tmax:integer,
      capa:integer)
```

### Arguments

| | |
|---|---|
| `resource` | the resource |
| `tmin` | lowerbound of the time interval |
| `tmax` | upperbound of the time interval |
| `capa` | the maximal amount of processing units available of resource in the interval [tmin,tmax] |

### Example

The following example shows how to use setcapacity:



```
model "Resource capacity"
 uses "kalis"

 declarations
  A, B, C : cptask              ! Declaration of tasks
  resource : cpresource         ! Declaration of resource
 end-declarations

 setname(A,"A"); setname(B,"B"); setname(C,"C")

! The resource is a cumulative resource with maximum capacity 6
 set_resource_attributes(resource, KALIS_DISCRETE_RESOURCE, 6)

! Setting the resource capacity in the interval 0..2 to 3
 setcapacity(resource, 0, 2, 3)
! Setting the resource capacity in the interval 3..4 to 2
 setcapacity(resource, 3, 4, 2)
! Setting the resource capacity in time period 5 to 1
 setcapacity(resource, 5, 5, 1)

! Setting the task durations
 set_task_attributes(A, 1)
 set_task_attributes(B, 2)
 set_task_attributes(C, 3)

! Setting the resource requirements of the tasks
 requires(A, 1, resource)
 requires(B, 2, resource)
 requires(C, 3, resource)
```

```
! Find the optimal schedule (minimizing the makespan)
 if cp_schedule(getmakespan) <> 0 then
  cp_show_sol
 else
  writeln("no solution found")
 end-if

end-model
```

### Related topics

set_resource_attributes

## getcapacity

### Purpose

Gets the maximal capacity (the maximal amount of processing units available) of a resource between two time bounds.

### Synopsis

```
function getcapacity(resource:cpresource, tmin:integer, tmax:integer,
        capa:integer) :  integer
```

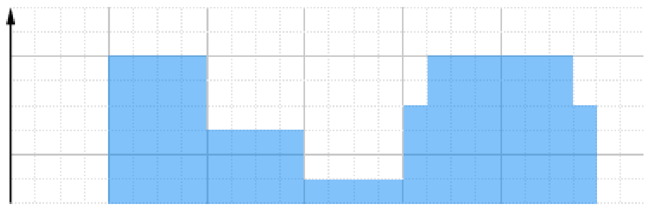
### Arguments

`resource` the resource

`tslot` lowerbound of the time interval

### Example

The following example shows how to use getcapacity:



```
model "Resource capacity"
 uses "kalis"

 declarations
  A, B, C : cptask              ! Declaration of tasks
  resource : cpresource         ! Declaration of resource
 end-declarations

 setname(A,"A"); setname(B,"B"); setname(C,"C")

! The resource is a cumulative resource with maximum capacity 6
 set_resource_attributes(resource, KALIS_DISCRETE_RESOURCE, 6)

! Setting the resource capacity in the interval 0..2 to 3
 setcapacity(resource, 0, 2, 3)
! Setting the resource capacity in the interval 3..4 to 2
 setcapacity(resource, 3, 4, 2)
! Setting the resource capacity in time period 5 to 1
 setcapacity(resource, 5, 5, 1)

! Setting the task durations
 set_task_attributes(A, 1)
 set_task_attributes(B, 2)
 set_task_attributes(C, 3)

! Setting the resource requirements of the tasks
 requires(A, 1, resource)
 requires(B, 2, resource)
 requires(C, 3, resource)

! Find the optimal schedule (minimizing the makespan)
 if cp_schedule(getmakespan) <> 0 then
```

```
  cp_show_sol
 else
  writeln("no solution found")
 end-if

end-model
```

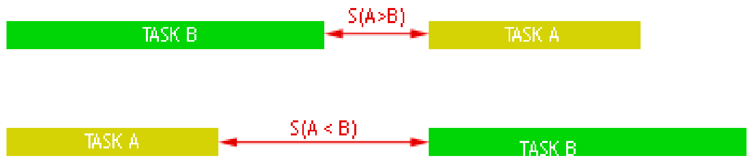
### Related topics

setcapacity

# setsetuptime

### Purpose

Sets sequence dependent setup times between two tasks. The setup time depends on the relative execution order in the schedule of the two tasks.




### Synopsis

```
procedure setsetuptime(task1:cptask, task2:cptask, task1_before_-
      task2:integer, task2_before_task1:integer)
```

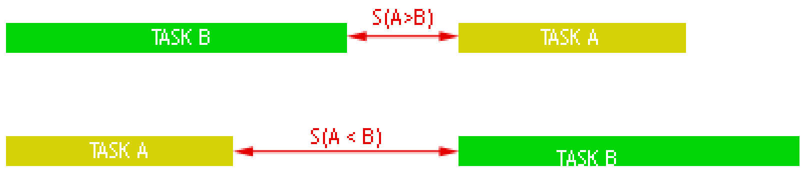
### Arguments

| | |
|---|---|
| `task1` | a task |
| `task2` | another task |
| `task1_before_task2` | setup time between the two tasks if task1 prececedes task2 |
| `task2_before_task1` | setup time between the two tasks if task2 prececedes task1 |

# getsetuptime

## Purpose

Return the sequence dependent setup times between task1 and task2 if task1 precedes task2. The setup time depends on the relative execution order in the schedule of the two tasks.




## Synopsis

```
function getsetuptime(task1:cptask, task2:cptask) :  integer
```

## Arguments

| | |
|---|---|
| `task1` | a task |
| `task2` | another task |

## is_fixed

### Purpose

Returns `true` if the status of the disjunction passed in argument is known.

### Synopsis

```
function is_fixed(disj:cpctr) : boolean
```

### Argument

`disj` the disjunction

### Return value

`true` if disjunction is fixed

### Example

The following example shows how to see if a cpctr `disj` is fixed

```
if is_fixed(disj) then
 write('status of disj is known')
end-if
```

### Related topics

`setpriority` `getpriority`

## cp_set_schedule_strategy

### Purpose

The cp_schedule search algorithm is decomposed in two distinct phases. The first phase target the finding of an near optimal heuristic solution quiclly. The second and last phase focuses on improving the bound and prove optimality.

### Synopsis

```
procedure cp_set_schedule_strategy(phase:integer, branching:cpbranching)
```

### Arguments

`phase` algorithm phase `KALIS_INITIAL_SOLUTION`,`KALIS_OPTIMAL_SOLUTION`

`branching` the search strategy

### Example

The following example shows how to set the search stragey for the cp_schedule function

```
cp_set_schedule_strategy(KALIS_INITIAL_SOLUTION,
          assign_var(KALIS_SMALLEST_MIN,KALIS_MIN_TO_MAX))
```

### Related topics

`KALIS_INITIAL_SOLUTION` `KALIS_OPTIMAL_SOLUTION` `cp_schedule`

# cp_get_default_schedule_strategy

### Purpose

The cp_schedule search algorithm is decomposed in two distinct phases. The first phase target the finding of an near optimal heuristic solution quiclly. The second and last phase focuses on improving the bound and prove optimality.

### Synopsis

```
procedure cp_get_default_schedule_strategy(phase:integer,
      branching:cpbranching)
```

### Arguments

`phase` algorithm phase (`KALIS_INITIAL_SOLUTION`,`KALIS_OPTIMAL_SOLUTION`)

`branching` the search strategy

### Example

The following example shows how to set the search stragey for the cp_schedule function

```
cp_set_schedule_strategy(KALIS_INITIAL_SOLUTION,
          assign_var(KALIS_SMALLEST_MIN,KALIS_MIN_TO_MAX))
```

### Related topics

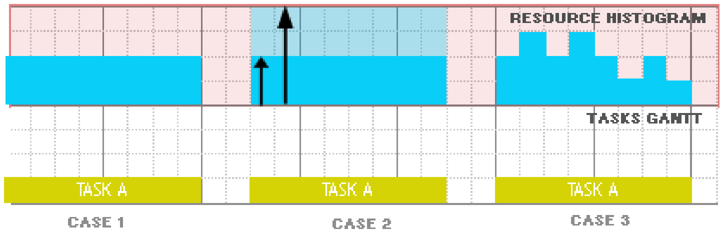
`KALIS_INITIAL_SOLUTION` `KALIS_OPTIMAL_SOLUTION` `cp_schedule`

## resusage

### Purpose

Create a resource usage. A resource usage is a means to specify the way that a resource will be produced/consumed/provided/required by a task. Three types of resource usages can be used :




- **CASE 1: Constant resource usage**. This is the simplest case where the resource usage is constant all along the execution of the task. For example a task A will require 2 units of resource R during its execution.
- **CASE 2: Variable resource usage but constant over the execution of the task**. This case allows the resource usage to be variable but constant during the execution of the task. Therefore, a decision variable is associated with the resource usage that can be constrained like any other variable. For example a task A will require between 2 units and 4 units of resource R during its execution.
- **CASE 3: Variable resource usage over the execution of the task**. This case allows the resource usage to vary during the execution of the task using a resource usage profile defined as a list of integers. For example a task A will require [2,3,2,3,2,1,2,1] resource units wich means '2' for the first timestep of its execution; '3' for the second *etc.*. If the duration of the task exceeds the length of the profile, then the resource usage is considered as 0 after the end of the profile. If the task duration is smaller than the length of the profile, the profile will be truncated to the duration of the task.

### Synopsis

```
function resusage(resource:cpresource, usage:integer) :  cpresusage
function resusage(resource:cpresource, usagemin:integer, usagemax:integer)
       :  cpresusage
function resusage(resource:cpresource, profile:array of integer) :
       cpresusage
```

### Arguments

`resource` the resource

`usage` the constant resource usage

`usagemin` minimal resource usage

`usagemax` maximal resource usage

`profile` profile of resource usage

### Example

The following example illustrates this:

```
Scheduling tasks with non-constant resource usage profiles.



(c) 2008 Artelys S.A. and Fair Isaac Corporation
```

```
*****************************************************************!)
model "Non constant resource usage"
 uses "kalis"

 forward procedure print_solution(tasks: set of cptask,
                                  resources: set of cpresource)

 declarations
  res1,res2: cpresource
  taska,taskb,taskc: cptask
 end-declarations

 taska.start    <= 15
 taska.duration = 4
 taskb.start    <= 15
 taskb.duration = 3
 taskc.start    <= 15
 taskc.duration = 5

! Define a discrete resource with periods of unavailability
 set_resource_attributes(res1, KALIS_DISCRETE_RESOURCE, 6)
 setcapacity(res1, 0, 15, 0)
 setcapacity(res1, 1, 5, 6)
 setcapacity(res1, 7, 11, 6)

 requires(taska, {resusage(res1,[1,3,5,6])})
 requires(taskb, {resusage(res1,[5,3,1])})
 requires(taskc, {resusage(res1,1,1)})
```

```
! Define a resource with initial capacity at 0
 set_resource_attributes(res2, KALIS_DISCRETE_RESOURCE, 0)

 provides(taska, resusage(res2,[1,3,1,2]))
 consumes(taskb, resusage(res2,[3,1,2]))
 produces(taskc, resusage(res2,[3,1,2,0,2]))

 if not cp_propagate then
  writeln("Problem is infeasible"); exit(1)
 end-if

 while (cp_find_next_sol) do
  print_solution({taska,taskb,taskc},{res1,res2})
 end-do

!-------------------------------------------------------------
!**** Display results ****
 procedure print_solution(tasks: set of cptask,
                         resources: set of cpresource)

  forall(res in resources) do
   writeln("Resource ", res.name)
   forall(timeindex in 0..getub(getmakespan)) do
    write(strfmt(timeindex,3), " Cap: ", getcapacity(res,timeindex))

    forall(t in tasks)
     if getrequirement(t,res,timeindex)>0 then
```

```
            write(", ", t.name, "(req):", getrequirement(t,res,timeindex))
           elif getproduction(t,res,timeindex)>0 then
            write(", ", t.name, "(prod):", getproduction(t,res,timeindex))
           elif getconsumption(t,res,timeindex)>0 then
            write(", ", t.name, "(cons):", getconsumption(t,res,timeindex))
           elif getprovision(t,res,timeindex)>0 then
            write(", ", t.name, "(prov):", getprovision(t,res,timeindex))
           end-if

          writeln
         end-do
        end-do

       end-procedure

      end-model
```

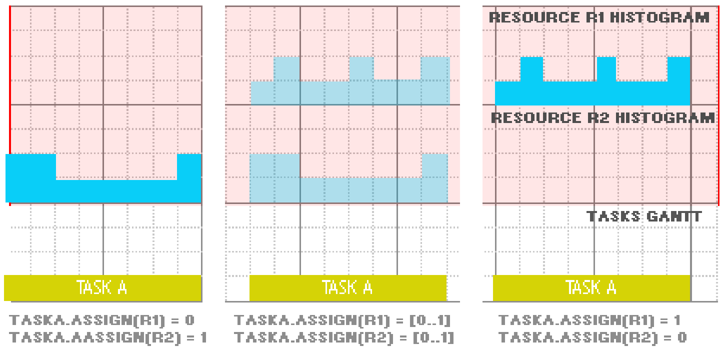
### Related topics

set_task_attributes

# getassignment

## Purpose

Gets the cpvar representing the assignment of a task for a particular resource. In the following example, either task A requires resource R1 with resource profile [1,2,1,1,2,1,1,2], or task A requires resource R2 with resource profile [2,2,1,1,1,1,1,2]. The choice depends on the value of the decision variables A.assignment(R1) and A.assignment(R2) that can both take a value of 0 (the task is not assigned to this resource) or a value of 1 (the task is assigned to this resource).




## Synopsis

```
function getassignment(task:cptask, resource:cpresource) :  cpvar
```

## Arguments

`task` the task

`resource` the resource

## Return value

The cpvar representing the assignment of 'task' to 'resource'

## Example

The following example illustrates this:

```
          Scheduling tasks with non-constant resource usage profiles.


          (c) 2008 Artelys S.A. and Fair Isaac Corporation


 *****************************************************************!)

 model "Alternative resources and non constant resource usage"

  uses "kalis"


  declarations

   res1,res2    : cpresource

   taskа,taskb : cptask
```

```
  arr1,arr2   : list of integer
 end-declarations

! Fix start times and durations
 taska.start   = 3
 taska.duration = 4
 taskb.start   = 3
 taskb.duration = 4

! Define 2 cumulative resources
 set_resource_attributes(res1, KALIS_DISCRETE_RESOURCE, 4)
 set_resource_attributes(res2, KALIS_DISCRETE_RESOURCE, 4)

 setname(taska,"taska"); setname(taskb,"taskb")
 setname(res1,"R1"); setname(res2,"R2")

! Define alternative resources for both tasks
 arr1 := [1,3,2,3]
 arr2 := [2,4,1,3]
 requires(taska, {resusage(res1,arr1),resusage(res2,arr2)}, 1, 1)
 requires(taskb, {resusage(res1,1,1),resusage(res2,1,1)}, 1, 1)

! Find all solutions
 while (cp_find_next_sol) do
  cp_show_sol
 end-do

end-model
```

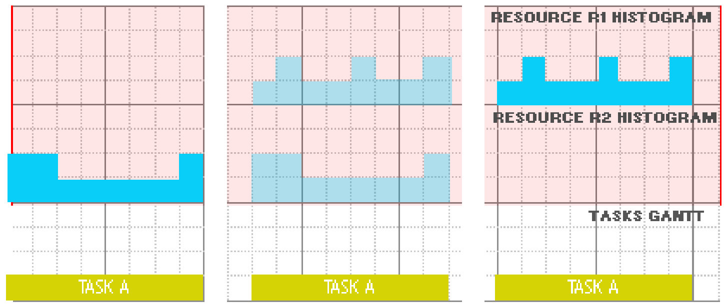
### Related topics

`has_assignment` `getstart` `getend` `getduration` `getconsumption` `getrequirement` `getproduction` `getprovision`

# has_assignment

## Purpose

In the following example, either task A requires resource R1 with resource profile [1,2,1,1,2,1,1,2], or task A requires resource R2 with resource profile [2,2,1,1,1,1,1,2]. The choice depends on the value of the decision variables A.assignment(R1) and A.assignment(R2) that can both take a value of 0 (the task is not assigned to this resource) or a value of 1 (the task is assigned to this resource).




## Synopsis

```
function has_assignment(task:cptask, resource:cpresource) : boolean
```

## Arguments

`task` the task

`resource` the resource

## Return value

`true` IFF a cpvar representing the assignment of 'task' to 'resource' exists

## Example

The following example illustrates this:

```
         Scheduling tasks with non-constant resource usage profiles.


         (c) 2008 Artelys S.A. and Fair Isaac Corporation


      *****************************************************************!)

      model "Alternative resources and non constant resource usage"

       uses "kalis"


       declarations

        res1,res2    : cpresource

        taska,taskb : cptask

        arr1,arr2    : list of integer
```

```
 end-declarations

! Fix start times and durations
 taska.start   = 3
 taska.duration = 4
 taskb.start   = 3
 taskb.duration = 4

! Define 2 cumulative resources
 set_resource_attributes(res1, KALIS_DISCRETE_RESOURCE, 4)
 set_resource_attributes(res2, KALIS_DISCRETE_RESOURCE, 4)

 setname(taska,"taska"); setname(taskb,"taskb")
 setname(res1,"R1"); setname(res2,"R2")

! Define alternative resources for both tasks
 arr1 := [1,3,2,3]
 arr2 := [2,4,1,3]
 requires(taska, {resusage(res1,arr1),resusage(res2,arr2)}, 1, 1)
 requires(taskb, {resusage(res1,1,1),resusage(res2,1,1)}, 1, 1)

! Find all solutions
 while (cp_find_next_sol) do
  cp_show_sol
 end-do

end-model
```

### Related topics

`getassignment` `getstart` `getend` `getduration` `getconsumption` `getrequirement` `getproduction` `getprovision`

## setidletimes

### Purpose

Specify the set of timesteps during which a resource should be considered as idle. When a task overlaps an idle timestep, resource usages are shifted to the right provided that the task duration is variable.

### Synopsis

```
procedure setidletimes(resource:cpresource, idleTimeSteps:  set of integer)
```

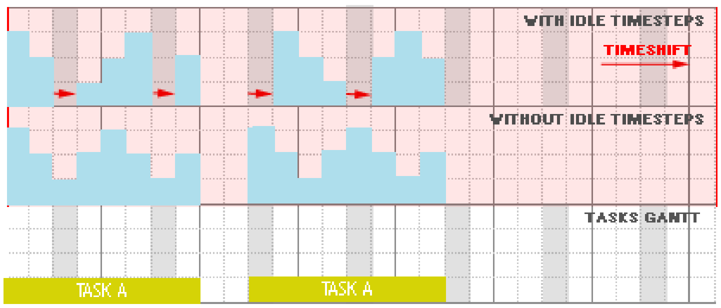
### Arguments

`resource` the resource

`idleTimeSteps` The set of idle time steps

### Example

Here is an example:




### Related topics

consumes requires provides produces resusage is_idletime

# is_idletime

**Purpose**

Test whether a specific timestep is defined as an idle time for the resource passed in the argument.

**Synopsis**

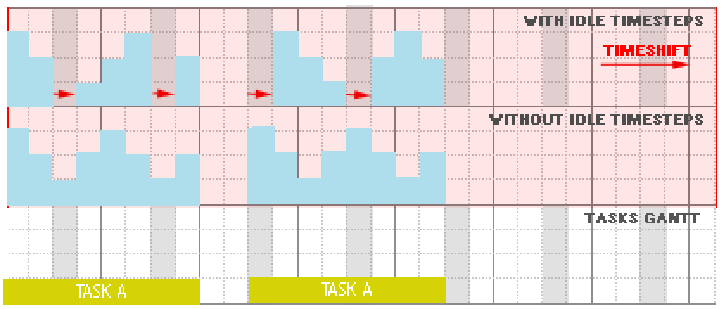
```
function is_idletime(resource:cpresource, timestep:  integer) :  boolean
```

**Arguments**

| | |
|---|---|
| `resource` | the resource |
| `timestep` | The time step |

**Example**

Here is an example:




**Related topics**

`consumes` `requires` `provides` `produces` `resusage` `is_idletime`

## 9.8 Linear relaxations

# KALIS_LARGEST_REDUCED_COST

### Purpose

Get a largest reduced cost variable selector from a linear relaxation solver

### Synopsis

```
procedure KALIS_LARGEST_REDUCED_COST(relaxationSolver:cplinrelaxsolver)
```

### Argument

`relaxationSolver` the linear relaxation solver

### Example

The following example shows how to use this function with a specific relaxation solver

```
cp_set_branching(assign_var(KALIS_LARGEST_REDUCED_COST(mysolver),
                            KALIS_NEAREST_RELAXED_VALUE(mysolver)))
```

### Related topics

KALIS_NEAREST_RELAXED_VALUE cp_set_branching

## KALIS_NEAREST_RELAXED_VALUE

**Purpose**

Get a nearest relaxed value selector from a linear relaxation solver

**Synopsis**

```
procedure KALIS_NEAREST_RELAXED_VALUE(relaxationSolver:cplinrelaxsolver)
```

**Argument**

`relaxationSolver` the linear relaxation solver

**Example**

The following example shows how to use this function with a specific cplinrelaxsolver

```
cp_set_branching(assign_var(KALIS_LARGEST_REDUCED_COST(mysolver),
                            KALIS_NEAREST_RELAXED_VALUE(mysolver)))
```

**Related topics**

`KALIS_LARGEST_REDUCED_COST` `cp_set_branching`

## cp_get_linrelax

**Purpose**

Returns an automatic relaxation of the cp problem

**Synopsis**

```
function cp_get_linrelax(orientation:  integer) :  cplinrelax
function cp_get_linrelax(orientation:  integer, constraints:  set of
       integer) :  cplinrelax
```

**Arguments**

`orientation` 0 for an 'LP oriented' relaxation (convex hull) and 1 for a 'MIP oriented' relaxation (can be an exact representation of the underlying cp problem)

`constraints` the set of constraints types to relax (`KALIS_LINEAR_CONSTRAINTS`, `KALIS_LOGICAL_CONSTRAINTS`, `KALIS_DISTANCE_CONSTRAINTS`, `KALIS_NON_LINEAR_CONSTRAINTS`, `KALIS_ALL_CONSTRAINTS`)

**Return value**

A linear relaxation

**Example**

The following example shows how to use the obtain a 'MIP oriented' relaxation by relaxing only the linear part of the problem and the logical constraints.

```
relax := cp_get_linrelax(1,{KALIS_LINEAR_CONSTRAINTS,
                            KALIS_LOGICAL_CONSTRAINTS})
```

**Related topics**

`get_linrelax_solver` `cp_add_linrelax_solver`

# get_linrelax_solver

### Purpose

Returns a linear relaxation solver from a linear relaxation, an objective variables and some configuration parameters

### Synopsis

```
function get_linrelax_solver(linrelax:cplinrelax, objective:cpvar,
      sense:integer, solvingType:integer, before_event:proc, must_-
      relax:proc, after_event:proc) :  cplinrelaxsolver
function get_linrelax_solver(linrelax:cplinrelax, objective:cpfloatvar,
      sense:integer, solvingType:integer, before_event:proc, must_-
      relax:proc, after_event:proc) :  cplinrelaxsolver
function get_linrelax_solver(linrelax:cplinrelax, objective:cpvar,
      sense:integer, solvingType:integer, configuration:integer) :
      cplinrelaxsolver
function get_linrelax_solver(linrelax:cplinrelax, objective:cpfloatvar,
      sense:integer, solvingType:integer, configuration:integer) :
      cplinrelaxsolver
function get_linrelax_solver(linrelax:cplinrelax, objective:cpvar,
      sense:integer, solvingType:integer, cpvarsToBeInstantiated:set
      of cpvar, floatvarsToBeInstantiated:set of cpfloatvar) :
      cplinrelaxsolver
function get_linrelax_solver(linrelax:cplinrelax, objective:cpfloatvar,
      sense:integer, solvingType:integer, cpvarsToBeInstantiated:set
      of cpvar, floatvarsToBeInstantiated:set of cpfloatvar) :
      cplinrelaxsolver
```

### Arguments

| | |
|---|---|
| `relax` | the linear relaxation |
| `objective` | the objective variable |
| `sense` | `KALIS_MINIMIZE` for minimization or `KALIS_MAXIMIZE` for maximization |
| `solvingType` | `KALIS_SOLVE_AS_LP` or `KALIS_SOLVE_AS_MIP` |
| `before_event` | a user callback triggered before the relaxation is solved |
| `must_relax` | a user callback saying when to solve the relaxation |
| `after_relax` | a user callback triggered after the resolution of the relaxation |
| `configuration` | One of the three predefined configurations (`KALIS_TOPNODE_RELAX_SOLVER`, `KALIS_TREENODE_RELAX_SOLVER`, or `KALIS_BILEVEL_RELAX_SOLVER`) |
| `cpvarsToBeInstantiated` | the set of cpvar to be instantiated before the resolution of the relaxation for a KALIS_BILEVEL_RELAX_SOLVER |
| `floatvarsToBeInstantiated` | the set of cpfloatvar to be instantiated before the resolution of the relaxation for a KALIS_BILEVEL_RELAX_SOLVER |

### Return value

A linear relaxation solver

## fix_to_relaxed

### Purpose

This method can be called during the tree search process to instantiate all the continuous variables to their values in the optimal solution of a relaxation.

### Synopsis

```
procedure fix_to_relaxed(linrelaxSolver:cplinrelax)
```

### Argument

`linrelaxSolver` the linear relaxation solver

### Example

The following example shows how to use the fix_to_relaxed method.

```
fix_to_relaxed(linrelaxSolver)
```

### Related topics

`get_relaxed_value`

## set_verbose_level

**Purpose**

Set the verbose level for a specific linear relaxation solver

**Synopsis**

```
procedure set_verbose_level(linrelaxSolver:cplinrelaxsolver, flag:boolean)
```

**Arguments**

`linrelaxSolver` the linear relaxation solver

`flag` value `true` or `false` to enable/disable output printing

**Example**

The following example shows how to use the set_verbose_level function.

```
set_verbose_level(linrelaxSolver,true)
```

**Related topics**

`get_linrelax_solver`

# cp_show_relax

**Purpose**

Pretty printing of the linear relaxation to the standard output.

**Synopsis**

```
procedure cp_show_relax(relax:cplinrelax)
```

**Argument**

`relax` the linear relaxation to be printed

**Example**

The following example shows how to use the cp_show_relax method.

```
cp_show_relax(relax)
```

**Related topics**

`cp_show_var` `cp_show_stats` `cp_show_prob`

## cp_add_linrelax_solver

### Purpose

Add a linear relaxation solver to the linear relaxation solver list.

### Synopsis

```
procedure cp_add_linrelax_solver(mylinrelaxsolver:cplinrelaxsolver)
```

### Argument

`linrelaxSolver` the linear relaxation solver to add

### Example

The following example shows how to use the cp_add_linrelax_solver function.

```
cp_add_linrelax_solver(mylinrelaxsolver)
```

### Related topics

get_linrelax_solver cp_clear_linrelax_solver cp_remove_linrelax_solver

## cp_remove_linrelax_solver

### Purpose

Remove a linear relaxation solver from the linear relaxation solver list

### Synopsis

```
procedure cp_remove_linrelax_solver(linrelaxsolver:cplinrelaxsolver)
```

### Argument

`linrelaxSolver` the linear relaxation solver to remove

### Example

The following example shows how to use the cp_remove_linrelax_solver function.

```
cp_remove_linrelax_solver(linrelaxsolver)
```

### Related topics

get_linrelax_solver cp_clear_linrelax_solver cp_add_linrelax_solver

# cp_clear_linrelax_solver

## Purpose

Clear the linear relaxation solver list

## Synopsis

```
procedure cp_clear_linrelax_solver
```

## Example

The following example shows how to use the cp_remove_linrelax_solver function.

```
cp_clear_linrelax_solver
```

## Related topics

get_linrelax_solver cp_remove_linrelax_solver cp_add_linrelax_solver

## get_indicator

**Purpose**

Get a 0,1 cpauxvar indicating wether the variable is instanciated (1) or not (0) to the given value.

**Synopsis**

```
function get_indicator(var:cpvar,i:integer) :  cpauxvar
```

**Arguments**

`variable` the variable

`value` the value

**Return value**

A auxiliary relaxation variable

**Example**

The following example shows how to use the get_indicator function.

```
indvar:= get_indicator(var,i)
```

# get_linrelax

### Purpose

Get the linear relaxation for a constraint.

### Synopsis

```
function get_linrelax(ctr:cpctr, type:integer) :  cplinrelax
```

### Arguments

| | |
|---|---|
| `ctr` | the constraint to relax |
| `type` | 0 for a 'LP oriented' relaxation and 1 for a 'MIP oriented' one |

### Return value

A linear relaxation

### Example

The following example shows how to get a 'MIP oriented' linear relaxation of a constraint 'ctr'.

```
get_linrelax(ctr,1)
```

### Related topics

`cp_get_linrelax`

## export_prob

**Purpose**

Export the linear program from a linear relaxation solver to a text file in LP format.

**Synopsis**

```
procedure export_prob(linrelaxsolver:cplinrelaxsolver, name:string)
```

**Arguments**

`linrelaxSolver` the linear relaxation solver to remove

`name` a file name

**Example**

The following example shows how to use the export_prob function.

```
export_prob(mylinrelaxsolver, name)
```

**Related topics**

`cplinrelaxsolver` `get_linrelax_solver` `get_linrelax`

# get_reduced_cost

## Purpose

Get the reduced cost for a variable from a linear relaxation solver

## Synopsis

```
function get_reduced_cost(linsolver:cplinrelaxsolver, var:cpvar) :  real
function get_reduced_cost(linsolver:cplinrelaxsolver, var:cpfloatvar) :
       real
```

## Arguments

`linsolver` the linear relaxation solver to remove

`var` a CP variable

## Return value

The reduced cost value

## Example

The following example shows how to use the get_reduced_cost function.

```
rc := get_reduced_cost(linsolver, x)
```

## Related topics

`get_relaxed_value` `get_linrelax` `set_integer`

# get_relaxed_value

### Purpose

Returns the optimal relaxed value for a variable in a relaxation.

### Synopsis

```
function get_relaxed_value(linsolver:cplinrelaxsolver, var:cpvar) :  real
function get_relaxed_value(linsolver:cplinrelaxsolver, var:cpfloatvar) :
       real
```

### Arguments

| | |
|---|---|
| `linsolver` | the linear relaxation solver to remove |
| `var` | a CP variable |

### Return value

The relaxation solution value

### Example

The following example shows how to use the get_relaxed_value function.

```
rv := get_relaxed_value(linsolver, x)
```

### Related topics

get_reduced_cost get_linrelax set_integer

## set_integer

**Purpose**

This method set a variable as integral in a linear relaxation

**Synopsis**

```
procedure set_integer(relax:cplinrelax, var:cpauxvar, global:boolean)
procedure set_integer(relax:cplinrelax, var:cpvar, global:boolean)
```

**Arguments**

`relax` a linear relaxation

`var` a relaxation variable

`global` `true` for a discrete variable, `flase` otherwise

**Example**

The following example shows how to use the set_integer function.

```
set_integer(myrelax, xaux, true)
```

**Related topics**

`get_relaxed_value` `get_reduced_cost` `get_linrelax`

# Bibliography


[BR01] C. Bessière and J.-C. Régin. Refining the Basic Constraint Propagation Algorithm. In *Proceedings of IJCAI-01*, pages 309—315, Seattle, 2001.

[CL94a] Y. Caseau and F. Laburthe. Cumulative Scheduling with Task Intervals. In *Joint International Conference and Symposium on Logic Programming*, 1994.

[CL94b] Y. Caseau and F. Laburthe. Improved CLP Scheduling with Task Intervals. In *ICLP94 Proceedings of the Eleventh International Conference on Logic Programming, MIT Press*, pages 369—383, 1994.

[LP96] C. Le Pape. Edge-Finding Constraint Propagation Algorithms for Disjunctive and Cumulative. In *Proceedings of the 15th Workshop of the U.K. Planning and Scheduling Special Interest Group*, pages 17—22, Liverpool, 1996.

[MVH08] L. Mercier and P. Van Hentenryck. Edge Finding for Cumulative Scheduling. *INFORMS Journal on Computing*, 20:143—153, 2008.

[Ŕ94] J.-C. Régin. A Filtering Algorithm for Constraint of Difference in CSPs. In *Proceedings of AAAI94*, pages 362—367, Seattle, 1994.

# Index