



# Mascotte: A few Maple Routines for Real-Time Code Generation

Thierry Viéville

► **To cite this version:**

Thierry Viéville. Mascotte: A few Maple Routines for Real-Time Code Generation. RR-2826, INRIA. 1996. inria-00073866

**HAL Id: inria-00073866**

**<https://hal.inria.fr/inria-00073866>**

Submitted on 24 May 2006

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

***Mascotte : A few Maple Routines for Real-Time Code  
Generation***

Thierry Viéville

**N 2826**

Mars 1996

————— THÈME 3 —————



***rapport  
de recherche***



# Mascotte : A few Maple Routines for Real-Time Code Generation

Thierry Viéville

Thème 3 — Interaction homme-machine,  
images, données, connaissances  
Projet RobotVis

Rapport de recherche n2826 — Mars 1996 — 38 pages

## Abstract:

The Mascotte Maple Package has been built to simplify the implementation of reactive software modules in vision and robotics and to facilitate the exchanges of data models and algorithms between builders of such reactive systems, using the Maple Symbolic calculator.

The main contributions of this package are :

- Designing routines for text manipulation
- A small add-on for linear algebra manipulations
- Some functions for code generation
  - A formater for equations and logic expressions: `format()`
  - A tool to manipulate program ressources: `msobj()`
  - A C-code generator for straight-line programs: `convert(,C)`
  - A mechanism to design maple routines from formal specifications: `procdefine()`

**Key-words:** Elementary symbolic computations, Vision and Robotics, Code generation, Linear algebra

*(Résumé : tsvp)*

# Mascotte : Quelques Outils Maple pour la Génération de Code Temps-Réel

## Résumé :

Le package Mascotte a été construit pour simplifier l'implémentation de modules de vision ou de robotiques de type réactifs et pour faciliter l'échange de modèles de données et d'algorithmes entre les concepteurs de tels systèmes, ceci à partir du système Maple.

Les principales contributions de cet ensemble de routines sont la manipulation de textes en Maple, quelques routines d'algèbre linéaire et des mécanismes de génération de code.

En bref, une manière de montrer qu'un calculateur symbolique ne sert pas qu'à faire des "maths", mais à manipuler d'autres entités informatiques.

Les principales contributions de cette petite extension sont :

- Des routines de manipulation de texte
- Un petit complément du package d'algèbre linéaire
- Des pour la generation de code
  - Un formateur d'équations et d'expression logiques: `format()`
  - Un outil pour manipuler les ressources d'un programme: `msobj()`
  - Un générateur de code C pour des calculs sans boucle: `convert(,C)`
  - Un mécanisme pour générer des routines maple à partir de spécifications formelles: `procdefine()`

**Mots-clé :** Calcul Symbolique élémentaire, Vision et Robotique, Génération de code, Algèbre linéaire

# Contents

<b>1</b>	<b>Introduction</b>	<b>5</b>
<b>2</b>	<b>A short description of the Mascotte contribution</b>	<b>5</b>
<b>A</b>	<b>Programmer Guide</b>	<b>10</b>
A.1	mso . . . . .	10
A.2	saveinlib . . . . .	10
A.3	textread . . . . .	11
A.4	textwrite . . . . .	12
A.5	type[func] . . . . .	13
A.6	convert[TEXT] . . . . .	13
A.7	convert[maple2inert] . . . . .	14
A.8	textparse . . . . .	15
A.9	msobj . . . . .	16
A.10	convert[C] . . . . .	18
A.11	procdefine . . . . .	19
A.12	format . . . . .	21
A.13	cost . . . . .	25
A.14	linalg1 . . . . .	26
A.15	linalg[tilde] . . . . .	27
A.16	linalg[rot3d] . . . . .	28
A.17	linalg[subrank] . . . . .	29
A.18	linalg[gaussform] . . . . .	30
A.19	linalg[bezoutian] . . . . .	31
A.20	linalg[signature] . . . . .	33
A.21	linalg[evalsm] . . . . .	34
<b>B</b>	<b>User Guide</b>	<b>36</b>

# Index

convert[C], 17  
convert[maple2inert], 13  
convert[TEXT], 12  
cost, 24  
  
format, 20  
  
linalg1, 25  
linalg[bezoutian], 30  
linalg[evalsm], 33  
linalg[gaussform], 29  
linalg[rot3d], 27  
linalg[signature], 32  
linalg[subrank], 28  
linalg[tilde], 26  
  
mso, 9  
msobj, 15  
  
procdefine, 18  
  
saveinlib, 9  
  
textparse, 14  
textread, 10  
textwrite, 11  
type[func], 12

# 1 Introduction

The Mascotte Maple Package has been built to simplify the implementation of reactive software modules in vision and robotics and to facilitate the exchanges of data models and algorithms between builders of such reactive systems, using the Maple Symbolic Calculator.

It is divided into three parts :

- A small enhancement of some Maple routines.
- A tiny complement of the `linalg` package.
- A few set of routines to manipulate equations and pieces of code.

As far as the first part is concerned, we have tried to formalize the different patches and contribution made to some usual Maple routines in order to fit with our applications. We have only defined a new procedure for what can not be actually easily done using usual Maple routines, or what is rather tricky to program using Maple procedures and gain of being encapsulated.

As far as the second part is concerned, we have collected rather easy to program routines which are commonly used in linear algebra but where missing in the actual package. Some are very small, some are a bit more heavy. We have started to define some formal manipulation of vector and matrix, without using their components, which is often required.

As far as the third part is concerned, we are still in a development phase, the main available and stable routine being the `format()` procedure. Other routines will make this package grown in a near future.

From a user point of view, all these routines form a Maple extension called Mascotte and can be easily used and accessed via the www page :

```
<A HREF=
"http://www.inria.fr/robotvis/personnel/vthierry/mascotte/main.html"
> Mascotte Package </A>
```

as shown in the User-Guide Appendix of the document, the installation is easily done by adding an element to the `libname` environment variable and calling `with(mso)`, plus `with(linalg1)` if required.

The documentation can be consulted on line, via the `?mso` command.

## 2 A short description of the Mascotte contribution

### Improving `type(,function): type(,func)`

(see section A.5)

The routine `type(,function)` does not accept Maple built-in operators, such as `'+'`, `'*'` which behave as function such as `&+'` or `&*'`. Furthermore, we might want to restrict the selection to a given function, a subset of function, or a function with a certain number of argument. All this is implemented in `type(,func)`.

For instance `type(u,function)` and `op(0,u) = F` and `nops(u) = 3` is simply written `type(u,func(F,;`



## Improving `readline(): textread()`

(see section A.3).

The main idea here is to provide an interface, not only to read a line, but a whole text-file and put it in a TEXT data-structure. This is a very simple routine but, extensively used in the sequel.

## Improving `writeto(): textwrite()`

(see section A.4).

The dual routine allows to store a TEXT data structure in a text-file. Contrary, to the previous routine it is not that trivial, and in particular allows to avoid some interface problems which occur when `writeto()` is manipulated, since only one file can be open at a time.

## Completing `save(lib|proc)(): saveinlib()`

(see section A.2).

Maple has hidden (!) procedures to help saving maple objects in a given library. We propose here a very simple and somehow powerfull mechanism to store a Maple object in the right place, including the help file.

## Completing `makehelp(): convert(,TEXT)`

(see section A.6).

The `makehelp()` allows to store a TEXT data structure corresponding to the help information of a Maple object. As a complement, `convert(,TEXT)` allows to generate such a data structure, by concatenation of portions of TEXT or strings, by executing some maple commands (see next paragraph), the result being in the TEXT.

It must be noted, that this routine uses temporary files in your local directory, and make use of `writeto()`, but in full compatibility with `writetext()`.

While `parse` executes a Maple command and output the result, the `&parse()` operator of `convert(,TEXT)` output the text of the command and its result in the TEXT data structure.

This routine is used to generate all help texts of this extension.

## Improving `define(): procdefine()`

(see section A.11).

The `define()` procedure provides a mechanism to automatically generates a procedure from a set of properties. The `procdefine()` procedure is a release of this standard Maple procedure but with the following improvements :

- It has no side effects, i.e. does not assign any object, but simply return the procedure with the desired behavior.
- It has a much higher number of algebraic properties which can be defined (for instance all what exists in symbolic computations can be easily defined here), including the remember option, or a call back to a standard maple procedure to complete the definition of the procedure.

- We have the feeling that `forall()` properties had a rather strange behavior in `define()` while `procdefine()` does not has this funny side effect.

This routine is extensively used in other parts of this extension.

## Improving `cost()`: `cost()`

(see section A.13).

A new version of the `cost()` function is proposed which simply accept non-algebraic expressions.

## An alternative to solve: simplifying equations with `format()`

(see section A.12).

Sometimes, the goal of a user is not to solve equations, but to put them in a better form. This what the rather huge procedure `format` attempts to do.

Considering equations and inequalities defined from logical operators, or composite equations, `format` apply all what is easy to do to simplify the equations :

- Logic operators are simplified,
- When the sign of an expression can be simplified, `format` uses it,
- Redundant equations are eliminated,
- Some syntactic compact forms are understood.

This routine has three applications:

- It put equations in a normal form and separate different components of the set of solution of these equations.
- It is a syntactic mechanism which allows to define complex problems via equations, with first-order logic operators and to reduce them.
- It contains several simplification rules to eliminate all trivial parts of the equations.

This allows, for instance, to evaluate the true complexity of a given problem, since all what is simple has been eliminated.

## Improving `C()`: `convert(,C)`

(see section A.10).

The philosophy of the `convert(,C)` function is completely different from what is found in `C()`. In our case:

- we do not generate C-lines code but a complete compilable C-routine, with its interface and a documentation of the source code (maple expression which is computed and computation cost);
- several non-algebraic expression are compiled, including logic expressions and conditional statements;

- the code is output as a TEXT data structure.

Maybe the drawback of our routine is that the generated code has a lot of parentheses, whereas in the C-lines generated by `C()` care is taken of having a minimal number of parentheses. So our code is less pretty. But how cares ?

This procedure allows to convert expressions to a "straight-line program" (slp) i.e. a piece of code which can be computed their input data being given with a constant execution time. The execution time is function of the data components sizes (and is a polynomial function of them). In such pieces of code, there is no random access to data structures and the index bounds can be evaluated, at compilation time. Such pieces of code never create a memory fault or an infinite loop and their semantic is easily defined.

## Improving `scanf()`: `textparse()`

(see section A.8).

While `scanf()` allows to parse lexical elements corresponding to numeric data structure or strings, `textparse()` is a Maple transcription of the lex/yacc mechanisms. It has a standard fixed lexical analyser and a parser which is entirely dynamic and can parse any context-free grammar. The parsing mechanism is -of course- not optimal, since it contains a form of backtracking, but is the best solution if we want to be able to change the grammar at will, which is the case here.

## Completing the `linalg` package: `linalg1`

(see section A.14).

Considering the rather extensive use of Maple in the field of computer vision and robotics we have been able to identify new `linalg` routines, often used. Some are very small, close to a macro, but save time and avoid repetitive mistakes. Some are more complex at the implementation level, but very standard in the field of algebra.

## Manipulating rotations: `tilde()`, `tilded()`, `rot3d()`

These routines allows to manipulate infinitesimal or non-infinitesimal 3D rotations. The parameterization of 3D rotations is a recurrent problem, and every-body has its own "best" solution. Here several solutions are proposed, including our "best solution", based on the non-real part of a unary quaternion (although the formalism of quaternions is totally avoided here).

## Specifying that a matrix is singular: `subrank()`

This simple routine allows to generate a minimal number of equations to insure that a given matrix is not of full rank. A valse with subdeterminants, nice to have in one box.

## Putting a symmetric matrix in its Gauss form: `gaussform()`

This very usefull routine allows to find a "diagonal" form for symmetric matrices: it is known that although every symmetric matrix has a diagonal form, the transformation being an orthogonal matrix, the algorithm to find this decomposition corresponds to the solution of an algebraic equation which is in general not possible, except for dimensions less than 5.

It is less known, that if we accept to have not an orthogonal matrix, but a less restrictive matrix of transformation, a triangular matrix in our case, we can find such a pseudo-diagonal form, from rational expressions only.

This problem is equivalent to put a second degree polynomial in a form where it appears as a sum of squares and both forms are available here.

An optimal form is found here, in the sense that among the different possible decompositions, the decomposition with the minimal cost is given.

### **Computing the Bezoutian: bezoutian()**

The Bezoutian of two polynomials is computed here.

### **Computing the signature of an object: signature()**

The signature of an expression (list of value, array, etc...) is somehow always easy to compute when the expression is numeric. When the expression involves variables, only a conditional expression can be issued. This is the case here, where the routine tries to output a simple conditional expression which evaluation corresponds to the given signature.

### **Formal manipulation of matrices and vectors: evalsm()**

There is often a need to manipulate vectors and matrices "without the components", especially in the case of Hilbert spaces, with infinite dimensions.

In fact several simplifications can be made, from symbolic algebraic properties of matrices as implemented in this routine.

However, we must remind that contrary to the polynomials for instance, the matrix algebra is very unfair: non-commutative, non-integral, etc... so that simplifications is more a heuristic than the generation of any pseudo-canonical form.

This might be the reason why "good" mathematicians have never program such a routine, while we have done it because we need it!

Furthermore, we have, in this routine, a formal derivator which can very easily simplify the computations of Jacobians.

## A Programmer Guide

### A.1 mso

#### HELP FOR:

Introduction to the Mascotte extension of the maple system

#### CALLING SEQUENCE:

```
with(mso)
```

#### SYNOPSIS:

- The Mascotte extension is a small set of maple routines which extend the capabilities of the actual maple system. They are made of functions to manipulate text structures, generate procedures, plus linalg functions.
- The objective of these functions is to generate reactive modules in robotics and vision systems, but may have also some other applications
- The presentation is a standard package, with some ‘‘readlib-defined’’ routines defined in it. It is thus simply loaded via `with(mso)`:
- The linalg package must be loaded using `with(linalg1)`. The trace function is renamed `proctrace` to avoid conflict with `linalg[trace]`
- Available routines in this extension are:

#### SEE ALSO:

```
proctrace, textread, textwrite, type[func], convert[TEXT],  
procdefine, format, cost, linalg1
```

### A.2 saveinlib

#### FUNCTION:

`saveinlib` - store a maple-object with its help in a library

#### CALLING SEQUENCE:

```
saveinlib(lib_name, obj_name)
```

**PARAMETERS:**

lib\_name - the name of the library in which the object is to be stored  
obj\_name - the name of the object to be stored

**SYNOPSIS:**

- saveinlib store a maple procedure and all its sub-objects and help file in a maple library.
- The obj\_name can be of the form 'name', or 'name1/name2'. Then all objects of name 'obj\_name' or 'obj\_name/\*' will be stored in the file of name 'lib\_name/obj\_name'. Furthermore the resulting help name will have the name 'help/text/name' or 'help/name1/text/name2' and be stored in the corresponding file, after conversion via convert[TEXT].
- Since you are a serious maple programmer, it always complains if no help file can be created.

**SEE ALSO:**

makehelp, convert[TEXT]

### A.3 textread

**FUNCTION:**

textread - read a text data structure from a file

**CALLING SEQUENCE:**

```
textread(filename)
```

**PARAMETERS:**

filename - the name of a file

**SYNOPSIS:**

- The function `textread()` returns the text read in the specified file.

It is returned as a text data structure of the form :

```
TEXT(  
    'line-1-of-text',  
    .../...  
)
```

#### SEE ALSO:

`TEXT`, `cat`, `textwrite`

## A.4 textwrite

#### FUNCTION:

`textwrite` - write a text data structure in a file

#### CALLING SEQUENCE:

```
textwrite(filename, text)
```

#### PARAMETERS:

<code>filename</code>	- the name of a file
<code>text</code>	- a text data structure of the form :

```
TEXT(  
    'line-1-of-text',  
    .../...  
)
```

#### SYNOPSIS:

- The function `textwrite()` writes the text into the specified file

#### SEE ALSO:

`TEXT`, `cat`, `writeto`

## A.5 type[func]

### FUNCTION:

type/func - generalized check for a function

### CALLING SEQUENCE:

type(expr,func(name,nbargs))

### PARAMETERS:

expr - any expression  
name - the name of the generalized function (optional)  
or a set of names of the generalized function  
nbargs - the number of arguments of the function (optional)

### SYNOPSIS:

- Check if the expression is a generalized function of eventually of a given name and eventually of a given number of argument(s).
- The following types: list, set, '+', '\*', '^', '=', '<>', '<', '<=', '\*\*', 'and', 'or', 'not' are considered as generalized function.

### SEE ALSO:

type[function]

## A.6 convert[TEXT]

### FUNCTION:

convert/TEXT - convert string or expr to a text data structure

### CALLING SEQUENCE:

convert(string,TEXT)

### PARAMETERS:

RR n2826



string - string or list of string or TEXT data structures  
with some possible unevaluated functions

## SYNOPSIS:

- This function attempts to construct a TEXT data structure from its argument. Each string is taken as a line of text. List of TEXT/string are concatenated.
- Strings may contain the following unevaluated functions:
  - '&cat'() which is the unevaluated form of cat()
  - '&parse'(string1,string2,...) which is a sequence of statements evaluated and put in the text as if run though a maple session. The '&parse' function is typically used in help text structure.
  - '&print'(expr1,expr2,...) to print maple expressions within the text.

## EXAMPLE:

Please run:

```
'convert/TEXT/example'();
```

## SEE ALSO:

TEXT, cat, textwrite, textread

## A.7 convert[maple2inert]

### FUNCTION:

```
convert/maple2msotext - convert a maple object to an msotext
convert/msotext2maple - convert an msotext to an maple object
convert/maple2inert   - convert a maple object to an inert form
convert/inert2maple   - convert back to a maple object
```

### CALLING SEQUENCE:

```
convert(expr, maple2msotext)
convert(text, msotext2maple)
convert(expr, maple2inert)
convert(expr, inert2maple)
```

### PARAMETERS:

expr - a maple exprssion.  
 text - a text data structure.

**SYNOPSIS:**

- These complementary pairs of functions allows to convert a maple object into :
  - \* an inert form, involving only string and function
  - \* an easily parsed text, as used by the mso C/C++ library.
- In fact, these routines are not really useful for a maple user, but are part of the interface with the C/C++ library.

**A.8 textparse**

**FUNCTION:**

textparse - defines a text parser via a formal grammar

**CALLING SEQUENCE:**

textparse(grammarrule1, grammarrule2, ...)

**PARAMETERS:**

grammarrule.i - an equation defining a grammar rule.

**SYNOPSIS:**

- The function textparse defines a maple procedure of the form:
 

```
proc(t:TEXT) ... end:
    which parses a TEXT data structure, according to a formal grammar.
```
- A lexical element of the grammar is defined by the regular expression:

```
[
]*                                     # which is skipped
(
  [@$%&]? [A-Za-z_]+ |
  ( [-]? ( [0-9]* [.] )? [0-9]+ ( [Ee] [+ -] [0-9] )? ) |
  [@$%&]? [+ - * % / ~ ^ = < > ? ! : | . ]+ |
  ( [ ' ] ( [ ' ] [ ' ] | [ ^ ' ] ) * [ ' ] ) | # not yet implemented
  [ " ] # $ 0 { [ ( ) ] }
```

- )
- The grammar is defined by a sequence of grammar rules of the form:  
`nonterminal(expr) = pattern`  
 where `expr` is an inert expression which represent the syntax structure and might contain some variables names as defined in the sequel  
 where a pattern is either a:
    - a sequence of (sub)pattern
    - any lexical element `&.(v)` where `v` is an optional variable name which will match the lexical element.
    - a string, corresponding to a given lexical unit
    - a nonterminal represented by an inert function with as optional argument, a variable name which will match the syntax structure
    - the `&*(pattern)` to denote 0, 1 or more occurrence of the pattern
    - the `&+(pattern)` to denote 1 or more occurrence of the pattern
    - the `&?(pattern)` to denote 0 or 1 occurrence of the pattern
    - the `&!([pattern1], [pattern2], ...)` operator to denote alternative, `[]` can be used to separate between different sequence of pattern.
  - The root of the grammar is the non-terminal of the first grammar rule.

### EXAMPLE:

```
> g := textparse(add(add(x,y))=&.(x),'+',&.(y)));
proc()
options 'I've been created with textparse() !!!',remember;
  if type(args[1],TEXT) then
    'textparse/yacc'(
      add,[add(add(x,y)) = (&.'(x),'+',&.'(y))], 'textparse/lex'(args[1])
    )
  else ERROR('Bad argument type')
  fi
end

> g(TEXT('a + b'));
                                add(a, b)
```

## A.9 msobj

### FUNCTION:

`msobj` - elementary mechanism of object definitions

### CALLING SEQUENCE

S:

```
msobj(obj, att [,satt...]) - to retrieve the value of an attribute
msobj(obj, att=val, ...) - to define the value of an attribute
```

## PARAMETERS:

```
obj - the name of an object
att - the name of an attribute
satt - the name of subattributes, either for dynamic attributes or
       to reference an attribute of a subobject.
val - any value
```

## SYNOPSIS:

- Provide an elementary mechanism of object definition.  
An object is defined by a list of attributes of a given value.  
The value of an object can be a name, an expression or another subobject.  
Objects are simply defined via Maple tables.
- Object reference : an object is referenced by its Name attribute, automatically inserted in the table. Therefore:  
‘type/msobj’ := u -> type(u,table) and u[Name]=u:
- Object heritage : when an attribute is undefined its default value is its own name, unless the attribute Type is defined. In this case, the value attribute is given by the first object in u[Type] which has this attribute defined.
- Object encapsulation : the attribute can itself be an object and referenced as such.
- Object dynamic attribute or methods : if an object value is a function then the value of the object is given by the evaluation of the function. Arguments of the functions are the sub-attributes

## EXAMPLE:

```
> msobj(myobj,a=1,b=hello,c=log(x-1)):
> op(myobj);
      table([
        a = 1
        b = hello
        c = ln(x - 1)
        Name = myobj
      ])

> msobj(yourobj,Type=[myobj,anotherobj],a=2,d=[1,2,3]):
> msobj(yourobj,a);
```

```
> msobj(yourobj,b);
                                hello

> msobj(yourobj,d);
                                [1, 2, 3]

> msobj(yourobj,e);
                                e
```

**SEE ALSO:**

assume, table

**A.10 convert[C]****FUNCTION:**

convert/C - convert an expression to a piece of C-code

**CALLING SEQUENCE:**

convert(expr, C, name)

**PARAMETERS:**

expr - an expression, an array of expression or a list of equations  
name - the name of the C-routine to be generated

**SYNOPSIS:**

- Convert the input to C code for evaluating it. It outputs a TEXT, which contains a full ANSI-C procedure.
- The input must be either:
  - a single algebraic, numeric or logic expression,
  - a named array of such expressions,
  - a list of equations of the form name = expression understood as a sequence of assignment statements.
- The output is always optimized, using:
  - the Maple optimize function
  - 23 digits constants for double precision
  - monodimensional arrays indexed from 0:  
(A[i,j,...] is replaced by `_A[(i-1)+(j-1)*rowdim(i)+...]`)

- The following "documentation" is provided in the code header:
  - The ANSI-C interface
  - The maple expression to be evaluated
  - The cost, i.e. the number of operations
- The following naming conventions are followed:
  - t0,t1,... variables are reserved for internal temporary variables
  - variables names starting with \_, e.g. \_a, \_M, are reserved for indexed variables
- Comparing to the original C() routine or one of its variant, this function manipulates less restrictive piece of codes, has a simpler interface and a better optimization. The conditional expression &if() is understood and used to translate logic expressions. However, the generated code is less "pretty" than with C(), e.g. parentheses are systematically inserted as in convert(string).

### EXAMPLES:

```
> s := ln(x)+2*ln(x)^2-ln(x)^3:
> textwrite('tmp1.c',convert(s,C,tmp1)):
> s := array([[x^2,ln(sin(x^2))],[sin(x^2),x^(-2)]]):
> textwrite('tmp2.c',convert(s,C,tmp2)):
> s := [v=&if(u>=0, u^2, csc(u^2)), w=v/cos(u^2), a[1]=arctan(w/f(u,w))]:
> textwrite('tmp3.c',convert(s,C,tmp3)):
```

### SEE ALSO:

optimize, cost, C, fortran, textwrite, TEXT

## A.11 procdefine

### FUNCTION:

procdefine - define an operator via properties and rules

### CALLING SEQUENCE:

```
procdefine(property1, property2, ...)
```

### PARAMETERS:

property.i - either name, equation or forall construct defining a property or a rule.

**SYNOPSIS:**

- `procdefine` defines a maple procedure of the form
 

```
proc(args) ... end:
via properties and rules.
```
- Contrary to `define()`, it has no side-effects, and does not affect functions such as `simplify`, `eval`, `expand`, `diff`, `series`, and `testeq`.
- Properties for the operator can be defined in a "declarative" way using this enhanced `forall` construct:
  - `forall({vars}, (f(args),cond) = res)` define rewriting rules, where
    - `{vars}` - is a list of names, eventually empty
    - `f(args)` - is the pattern on which this rule will be used. `f` must be the function defined by `procdefine`. It must often be in an inert form.
    - `cond` - is an (optional) inert boolean expression
    - `res` - is the desired result
  - The operator produces the expression `res` each time:
    - (1) the `[args]` pattern matches the operator arguments and
    - (2) the `cond` pre-condition is evaluated to true after substitution.
  - The names defined in `vars` are used as matching arguments which can take any possible value. The substitutions are then done for all possible such values.
  - To constrain an expression `x` to be of a certain type `t` and/or have a given property `p` as defined in the `assume` facility, the `cond` expression must contain a relation of the form:
 

```
'&is'(x,t)
```

 where the `is` function is given in a "frozen" form  
 Any other conditions can be introduced, using `procmake` syntax.
- Properties can also be defined in a "procedural" way via a standard maple procedure:
  - `procedure=p;` In that case the operator is also defined by a procedure of name `p` which will be called to evaluate the arguments.
- Otherwise the following properties are understood:
  - `remember;` The operator has the `remember` option
  - `unary;` The operator is unary and must have 1 argument.
  - `binary;` The operator is binary.
  - `type=t;` The argument(s) must be of the given type
  - `type=[t1,t2,...,tn];` Each arguments must be of the given type according to this list. The operator must have `n` arguments
  - `associative;` The operator is associative (`n`-ary), so  $f(x,f(y,z)) = f(f(x,y),z) = f(x,y,z)$ .
  - `commutative;` The operator `f` is commutative, so  $f(x,y) = f(y,x)$ . The arguments will be ordered to guarantee uniqueness.
  - `antisymmetric;` The operator `f` is antisymmetric, so  $f(x,y) = -f(y,x)$  and  $f(x,x)=0$ .
  - `idempotent;` The operator is idem-potent, so  $f(f(x)) = x$ , it is consider as a unary operator

- nopower; The operator reduces powers so,  $f(x,x) = f(x)$  such as in and/or boolean operators
- linear; Define the operator as being linear, i.e.:  
 $L(K1*a + K2*b, \dots) = K1*L(a, \dots) + K2*L(b, \dots)$  and  
 $L(K3, \dots) = K3*L(1, \dots)$   
for any constants  $K1$ ,  $K2$  and  $K3$ .
- zero=x; Define the zero to be  $x$ , so if any argument is  $x$  then the result is  $x$ .
- identity=x; The expression  $x$  is to be considered the left and right identity of the operator.
- inverse=g; Define the inverse left-side and right-side unary operator to be the operator  $g$ .
- power=g; Define the power binary operator to be the operator  $g$ , so  $f(x,x) = f(g(x,2))$ , etc...
- powerof=g; Define the this binary operator is the power of an operator  $g$
- derivative=[&g,...]; The operator is a derivative operator for the multiplicative operator(s)  $\&g, \dots$ , so if  $K1$ ,  $K2$  are constant, i.e. do not contain one of the derivative variable:  
 $L(K1*a + K2*b, \dots) = K1*L(a, \dots) + K2*L(b, \dots)$  and  $L(K1, \dots) = 0$   
while for the multiplicative operator(s)  
 $L(a \&g b, \dots) = a \&g L(b, \dots) + L(a, \dots) \&g b$
- scalarprod; The operator is mixed with scalar products, so:  
 $f(K * a, b) = K * f(a,b)$  for any constant or scalar  $K$
- expand=[g,...]; The operator left and right expanded over the operator(s)  $g, \dots$ , so  $f(\dots, g(y,z), \dots) = g(f(\dots, z, \dots), f(\dots, y, \dots))$  note that arguments of  $g$  are inverted.
- expandon=[g,...]; The operator left and right expanded over the operator(s)  $g, \dots$ , so  $f(\dots, g(y,z), \dots) = g(f(\dots, z, \dots), f(\dots, y, \dots))$  note that arguments of  $g$  are inverted AND  $expand()$  is map on arguments.
- verbosecall; The operator executes a `print('procname(args)')` on each call, for modular debugging purpose.

## SEE ALSO:

define, procmake, mso

## A.12 format

### FUNCTION:

format - format a set/logic expression of [in]equalities



**CALLING SEQUENCE:**

```
format(eqns)
format(eqns,real)
```

**PARAMETERS:**

```
eqns      - a system of real equations, either a set of equation
           or a boolean expression of equations.
real      - an optional directive to assume all variables are real.
```

**SYNOPSIS:**

- This function format a set of [in]equalities or a logic combination of these and attempt to reduce them to obtain a normal form.
- The final form is a `&or(&and( ... ))` expression, i.e. the union of conjunction of equations, unless quantificators occur.
- The real directive assumes that all variables are real. [In]equalities with complex values are false
- The following transformations are performed:
  - [In]qualities are expanded over vectors and matrices
  - [In]equalities are put in a normal form, i.e.:  
 $e = 0$ ,  $e <> 0$ ,  $e < 0$ ,  $0 > e$ ,  $e \leq 0$ ,  $e \geq 0$   
 and the sign of  $e$  is reduced (via `csgn`) when possible.
  - For complex expressions the sign is understood as for `csgn`.
  - For expressions with a denominator the constraint that the denominator is not zero is introduced.
- During the computation, we must set :  
`_Envsignum0 := 0;`  
 and restore its old value at the end, in order to get coherent sign values
- Logic expressions are simplified. They are builded from the following primary operators:
  - `&and(x,y)` means :  $x$  and  $y$
  - `&or(x,y)` means :  $x$  or  $y$
  - `&exists(v,x)` means : there exists variable(s)  $v$ , for which  $x$  is true
  - `&forall(v,x)` means : for all variable(s)  $v$ ,  $x$  is true
 and the following secondary operators, which are reduced:
  - `&not` `&implies` `&iff` `&nor` `&nand` `&xor`
  - In these operators  $x$  and  $y$  are [in]equalities or the boolean constant false or true, or subexpressions of these, while  $v$  is the name of a variable or a set of variable(s).
  - In this context `&and()` and `&or()` are commutative operators

evaluated in any order, contrary to the maple and/or operators.

- A set is taken as a &and operator and a sequence as a &or operator in order to be compatible with solve() outputs
- Conditional expression are simplified, using the operator:
  - &if(cond, expr-if-true, expr-if-false)
- The multi-arguments inter &if operator:
  - &if(cond1, expr1[, cond2, expr2[,cond3, expr3]]... expr0)
  - is reduced to the 3-arguments form. If the expr-if-false argument is omitted it takes the false value.
- The If() and 'if'() names of the operator are also accepted.
- The 'and' and 'or' operators are rewritten using &if:
  - x and y                    is rewritten as &if(x, y, false)
  - x or y                     is rewritten as &if(x, true, y)
- List of equations are taken as equation sequences.
- Several piece-wise continuous fonctions are rewritten using &if:
  - the maple inert functions Heaviside, Dirac, Signum, Csgn, Abs and :

Win(t) : Window Function        /

:   = 0	if t < -1	or t > 1
\ = 1	if t > -1 and t < 1	

Thr(t) : Threshold Function    / = t-1    if t > 1

:   = 0	if t > -1 and t < 1	
\ = t+1	if t < -1	

Sat(t) : Saturation Function   / = 1        if t > 1

:   = t	if t > -1 and t < 1	
\ = -1	if t < -1	

- Some nested constructions with relational operators are also allowed:
  - a < (b < c)        means (a < b) and (b < c)
  - a <> (b <> c)       means (a <> b) and (b <> c) and (c <> a)
  - a <> (b and c)     means (a <> b) and (a <> c)
  - d < &if(c,a,b) means &if(c,d<a,d<b)
  - a = (b or c)       means (a = b) and (a = c)
- etc ...
- The form &delete(expr,o) where o is a subset of {'<>', '<', '<='} allows to delete inequalities and transform them to equations, adding a new variable, as stated by the following rules:
  - f <> 0 <=> &exists( t, t \* f - 1 = 0)
  - f <= 0 <=> &exists( t, t^2 + f = 0)
  - f < 0 <=> &exists( t, t^2 \* f - 1 = 0)

## EXAMPLES:

```

> format({a*x+b*y=0,x=0,b<>0});
      &and(b <> 0, x = 0, y = 0)

> format({a<>(x &and y), If(u,v,w)=0});
      &and(a - x <> 0, &if(u, v = 0, w = 0), a - y <> 0)

> format(x=u*RootOf(_Z^2+4));
      (I x + 2 u = 0) &or (I x - 2 u = 0)

> format({(b<>c)<>(a=0),a<=0,a>=0,d+log(1+a)>=0});
      &and(b <> 0, a = 0, b - c <> 0, 0 <= d)

> format(array([a,b,c])=array([a,c,b]));
      b - c = 0

> format(&exists({x,y},&exists(z,x^3+z=0)));
      3
      {x, z} &exists (x + z = 0)

> format(&or(a^10<=0,a=0,-a=0,10*a=0,a+c^2*a=0),real);
      a = 0

> format({b*a>=0,b>=0,c^2+1>0,b^2-d^2=0},real);
      &or(&and(b - d = 0, 0 <= a, 0 <= b), &and(0 <= a, 0 <= b, b + d = 0),
      &and(a <= 0, b = 0, d = 0))

> format({d^8*c^2+d^10*b^2>=0,-c^4-a^8<=0},real);
      true

> format(&or(b=0,c<=0,&and(e=0,b<>0,c>0)));
      &or(b = 0, e = 0, c <= 0)

> format(&if(a and (b or not c), d, e));
      &if(a, &if(b, d, &if(&not c, d, e)), e)

> format(Thr(u-2)/Sat(v));
      &if(0 < - u + 1, &if(v + 1 < 0, 3 - u, &if(1 - v < 0, u - 3,  $\frac{u - 3}{v}$ )),
      &if(3 - u < 0, &if(v + 1 < 0, - u + 1, &if(1 - v < 0, u - 1,  $\frac{u - 1}{v}$ )), 0))

```

```
> format(&delete({x<0,y<>0}),real);
                2
      ({t0} &exists ((- x t0  + 1 = 0) = 0)) &and
      ({t1} &exists ((- y t1 + 1 = 0) = 0))
```

**SEE ALSO:**

csgn, signum, solve, logic, evalc, procdefine

**A.13 cost****FUNCTION:**

cost - (enhanced) operation evaluation count

**CALLING SEQUENCE:**

cost(e1, e2, ..., en)

**PARAMETERS:**

e1, e2 ... any expression(s)

**SYNOPSIS:**

- Cost is used to compute an operation count for the numerical evaluation of the given arguments. The operation count is expressed as a polynomial in the names additions, multiplications, divisions, functions, subscripts and assignments with non-negative integer coefficients. Comparisons or operations in logical expressions are considered as "assignments".
- Assignment of positive real values to these global names yields a weighted cost.
- Note that the cost used for computing powers is as follows. For an

integral power, repeated multiplication is assumed. For a general power it is assumed to be computed using `exp` and `ln`.

- This function is similar to the `maple cost` function except that it is valid also on logical expressions

## EXAMPLES:

```
> cost(x+x^2+x^3+x^4);
          3 additions + 6 multiplications

> cost(w=&if(a<>0,b+1,c-2));
          2 additions + functions + 2 assignments
```

## SEE ALSO:

`optimize`

## A.14 linalg1

### HELP FOR:

The `mso` extension to the `linalg` package

### CALLING SEQUENCE:

```
with(linalg1)
```

### SYNOPSIS:

- The `linalg1` pseudo-package is a small extension of the `linalg` package. It is loaded using `with(linalg1)` but all functions belong to `linalg`
- Using `with(linalg1)` the `linalg` package is loaded with additional routines
- The `trace` function is renamed `proctrace`, avoiding conflict with `linalg[trace]`
- Available additional routines are listed below :

**SEE ALSO:**

linalg, mso, linalg[tilde], linalg[tilded], linalg[rot3d],  
 linalg[gaussform], linalg[subrank], linalg[bezoutian],  
 linalg[signature], linalg[evalsm],

**A.15 linalg[tilde]****FUNCTION:**

tilde tilded - representation of a skew-symmetric matrix

**CALLING SEQUENCE**

S:

```
SkewSymmetricMatrix:=tilde(Vector)
Vector:=tilded(SkewSymmetricMatrix)
```

**PARAMETERS:**

SkewSymmetricMatrix : a skew-symmetric 3x3 matrix  
 Vector : a 3 dimensional vector

**SYNOPSIS:**

- tilde and tilded convert a vector V to a skew-symmetric matrix H such that :  $V \wedge x = H * x$ . We have :

$V = (X, Y, Z)$

$$H = \begin{pmatrix} 0 & -Z & Y \\ Z & 0 & -X \\ -Y & X & 0 \end{pmatrix}$$
**SEE ALSO:**

linalg - maple package for Linear Algebra.

## A.16 linalg[rot3d]

### FUNCTION:

rot3d - compute the matrix of a 3D-rotation

### CALLING SEQUENCE

S:

```
R:=rot3d(u,a)
R:=rot3d(v)
R:=rot3d(alpha,beta,gamma)
r:=rot3d(R)
r:=rot3d(R,'alpha','beta','gama')
```

### PARAMETERS:

R a rotation matrix  
u a unitary vector parallel to the axis of rotation  
a a scalar equal to the rotations angle  
v a vector parallel to the axis of rotation which norm is equal to  $2*\tan(a/2)$   
r a vector parallel to the axis of rotation which norm is equal to  $\sin(a)$ . We have  $r = 4/(4+v^2) v$ .  
alpha, beta, gama scalars equal to the Euler angles of the rotation  
'alpha','beta','gama' names equal to the Euler angles variables

### SYNOPSIS:

- rot3d computes the rotation matrix related to the unitary vector u and the angle a, if called with two parameters (trigonometric representation of the rotation).
- or
- rot3d computes the rotation matrix related to the vector v, as defined above, if called with one parameter (algebraic representation of the rotation).
- or
- rot3d computes the rotation matrix related to Euler angles defined as follows :

```
rot3d(array([1,0,0]), alpha) *
rot3d(array([0,1,0]), beta) *
rot3d(array([0,0,1]), gamma)
```
- or
- rot3d computes the rotation vector r related to matrix R

or

- rot3d computes the equations of the Euler angles related to matrix R

**EXAMPLE:**

```

> rot3d(array([0,0,1]),a);
      [ cos(a)  - sin(a)  0 ]
      [          ]
      [ sin(a)   cos(a)  0 ]
      [          ]
      [   0       0     1 ]

> rot3d(array([0,0,1]));
      [ 3/5  -4/5  0 ]
      [          ]
      [ 4/5   3/5  0 ]
      [          ]
      [  0     0   1 ]

> assume(beta>0);
      [ 3/5  -4/5  0 ]
      [          ]
      [ 4/5   3/5  0 ]
      [          ]
      [  0     0   1 ]

> rot3d(rot3d(alpha,beta,gama),Alpha,Beta,Gama);
      sin(gama)          sin(alpha)
{tan(Gama) = -----, tan(Alpha) = -----, sin(Beta) = sin(beta~)}
      cos(gama)          cos(alpha)

```

**SEE ALSO:**

linalg - maple package for Linear Algebra.

**A.17 linalg[subrank]**

**FUNCTION:**

subrank - generates equations for a matrix to be singular



**CALLING SEQUENCE:**

```
subrank(M)
```

**PARAMETER:**

M - a matrix

**SYNOPSIS:**

- subrank computes the set of equations which must vanish for the matrix to be singular i.e. not of full rank.
- If M is a square matrix the equation  $\{ \det(M) = 0 \}$  is returned, else a minimal set of minor to vanish is returned.

**EXAMPLE:**

```
> subrank(array([[t,0],[0,b],[a,0]]));  
           {t b = 0, - b a = 0}
```

**SEE ALSO:**

linalg - maple package for Linear Algebra.

**A.18 linalg[gaussform]****FUNCTION:**

linalg/gaussform - convert a symmetric matrix to its Gauss form

**CALLING SEQUENCE:**

```
gaussform(<matrix>)
```

**PARAMETERS:**

<matrix> - a symmetric matrix

**SYNOPSIS:**

- The Gauss decomposition of the nxn matrix is returned as a exprseq of two matrices in the following form : (L, P)  
where:
  - L is a diagonal matrix, i.e. n coefficients, which corresponds, to the diagonal of M in the general case (unless one diagonal element is zero)
  - P is upper-triangular matrix (unless all diagonal elements are 0) with 1 as diagonal terms, i.e.  $n(n-1)/2$  coefficients for the upper triangle, such that the  $n(n+1)/2$  coefficients of M are defined though:  $M = P^T L P$
- Such decompositions always exists and are in finite number, among them, the one which is the fastest to compute is returned.

**EXAMPLES:**

```
> P:=array([[1,2,4],[0,1,2],[0,0,1]]):
> L:=array([[a,0,0],[0,b,0],[0,0,c]]):
> M:=linalg[multiply](linalg[transpose](P),L,P);
      [ a      2 a      4 a      ]
      [
      [ 2 a   4 a + b   8 a + 2 b ]
      [
      [ 4 a   8 a + 2 b  16 a + 4 b + c ]

> G:=map(u->map(normal,u),gaussform(M));
      [ a  0  0 ] [ 1  2  4 ]
      [          ] [          ]
      [[ 0  b  0 ], [ 0  1  2 ]]
      [          ] [          ]
      [ 0  0  c ] [ 0  0  1 ]
```

**SEE ALSO:**

linalg

**A.19 linalg[bezoutian]**



**SEE ALSO:**

linalg, bezout, signature

**A.20 linalg[signature]****FUNCTION:**

linalg/signature - compute the signature of list of value

**CALLING SEQUENCE:**

signature(v [,t])

**PARAMETERS:**

v - a list, vector, symmetric-matrix or polynomial  
t - a variable t, for the case v is a polynomial

**SYNOPSIS:**

- Compute the signature of a list of values. A signature is the number of positive values minus the number of negative values.
- If the argument is a symmetric matrix, the signature of the diagonal of the Gauss decomposition of the matrix is returned.
- If the argument is a polynomial in one variable t, the signature of the Bezoutian of P, i.e. the number of real roots, is returned.
- If the values are not constant a conditional expression is returned.

**EXAMPLE:**

```
> signature([a,a*b]);
      &if(a = 0, 0, &if(a < 0, &if(b a = 0, -1, &if(b a < 0, -2, 0)),
          &if(b a = 0, 1, &if(b a < 0, 0, 2))) )
```

```
> signature(a*t^2+b*t+c,t);
      unable to execute seq
```

**SEE ALSO:**

linalg, bezoutian, gaussform

## A.21 linalg[evalsm]

### FUNCTION:

`linalg/evalsm` - perform a symbolic evaluation of `linalg` operators

### CALLING SEQUENCE:

`'linalg/evalsm'(<expr> [,expand])`

### PARAMETERS:

`<expr>` - a symbolic expression involving matrix and vector  
`expand` - a directive to require the expression to expanded

### SYNOPSIS:

- The function evaluate the following symbolic matrix operators :
  - `A + B` : addition of scalar/vector/matrix with 0 as unary element
  - `A &* B` : multiplication of scalar/vector/matrix with 1 as unary element
  - `s * B` : scalar multiplication
  - `A &^ n` : integer power of scalar/vector/matrix.
  - `&t(A)` : transpose of scalar/vector/matrix
  - `&x(u,v)` : the cross-product of two 3D-vectors
  - `&.(u,v)` : the dot-product of two vectors
  - `&D(A,X)` : differential of a scalar/vector/matrix with respect to  
a scalar/vector/matrix
  - `Det(A)` : determinant of a matrix
  - `Trace(A)` : trace of a matrix
- Note that a constant will be considered as a constant multiple of the identity matrix.
- The following properties of a matrix are used for simplification:
  - symmetric
  - antisymmetric
  - singular
  - idempotent
  - nilpotent
  - ScalarMatrix
  - orthogonal

- scalar  
as available via the `assume()` facility
- Unassigned names will thus be considered either as symbolic matrices  
or as scalars depending on their properties.

**EXAMPLES:**

```
> unassign('c','A','K','p','C','G','B','x','y','f','g');
> assume(c,scalar);
> assume(A,symmetric);
> evalsm(&*(&t(&t(&t(A))),1));
                                A~

> evalsm(&*(K &^ p, (Pi * K)));
                                Pi (K &^ (p + 1))

> evalsm(&*(C &^(-1),&t(&t(C)))+&*(&(1,K),G,K));
                                1 + &(K, G, K)

> evalsm(C+&*(&t(&t(G))+0)+(&*(&(1,K),K &^(-1)))-1-G);
                                C

> evalsm(&D(&*(&t(A),x)+x+B^y+c &* f(x) &* g(x),x));
                                A~ + 1 + c~ (((f(x) &D x) &* g(x)) + (f(x) &* (g(x) &D x)))

> evalsm(&t(A+c*(&t(B) + G &* F)),expand);
                                c~ ((&t F) &* (&t G)) + c~ B + A~

> evalsm(&t(A &* (&t(B) + c * G + F)),expand);
                                (B &* A~) + c~ ((&t G) &* A~) + ((&t F) &* A~)

> evalsm(&t(A &x (&t(B) &x &t(C))),expand);
                                (A~ &* C) B - (A~ &* B) C
```

**SEE ALSO:**

`procdefine`, `evalm`, `assume`

## B User Guide



The **Mascotte Maple Package** has been built to simplify the implementation of reactive software modules in vision and robotics and to facilitate the exchanges of data models and algorithms between builders of such reactive systems, using the Maple Symbolic calculator.

*Technical support:* [vthierry@sophia.inria.fr](mailto:vthierry@sophia.inria.fr) .

- To know more about Mascotte : [HERE](#) also available as ps-file .
- To access to the on-line Maple/Mso doc, just choose your subject:

and your request.

- To install Mascotte with your maple : [HERE](#)
  - To feedback to the Mascotte authors : [HERE](#)
-



In order to get this package, you must generate an additional Maple library, from the `make.map` source file, under the following copyright :

- If you are at INRIA-Sophia you just have to put the line :  
**libname := '/u/krakatoa/0/ftp/pub/html/vthierry/mascotte/lib', libname: with(mso):**  
 in your `$HOME\mapleinit` configuration file.
- If you are in a **Unix environment** :
  - Get the source file `make.map` and the script `mso-install` file, and store them in a suitable directory, that we will now call **MSO\_DIR** .
  - Run `mso-install` in this directory and add the line :  
**libname := MSO\_DIR, libname: with(mso):**  
 in the configuration file `$HOME\mapleinit` of the user(s).  
 You can easily maintain this package putting this `mso.makefile` in `MSO_DIR` .  
 More details on the installation can be found in `mso-install` .
- If you have a **MsDos PC-Compatible installation**, in the `c:/maplev3` directory :
  - Get the source file `make.map` and the script `install.bat` file, and store them in the same directory.
  - Run `install.bat` and add the line :  
**libname := 'c:/maplev3/mso/', libname: with(mso):**  
 in the configuration file `c:\maplev3\lib\maple.ini` of your maple installation.
  - Run your standard maple and enjoy it !  
 More details on the installation can be found in `install.bat` .
- If you have **Macintosh machine**, sail it, by a PC or a Unix machine and choose one of the items above.

Other source files, not in the library are also available:

- The `ugeometry` small set of routines for 2d and 3d geometry.
- More to come !





Please send report any bug, or suggestion :

- Your Email Address (**mandatory**):
- The subject of your message:
- The contents of your message:

---

*Acknowledgments :*

- We are thankfull to Michel Buffa for the small icons used in this page.
  - This work has been done in the RobotVis project, belonging to Robotic, Image and Vision program of the INRIA institute, located at Sophia Antipolis.
-



---

Unité de recherche INRIA Lorraine, Technopôle de Nancy-Brabois, Campus scientifique,  
615 rue du Jardin Botanique, BP 101, 54600 VILLERS LÈS NANCY  
Unité de recherche INRIA Rennes, Irista, Campus universitaire de Beaulieu, 35042 RENNES Cedex  
Unité de recherche INRIA Rhône-Alpes, 46 avenue Félix Viallet, 38031 GRENOBLE Cedex 1  
Unité de recherche INRIA Rocquencourt, Domaine de Voluceau, Rocquencourt, BP 105, 78153 LE CHESNAY Cedex  
Unité de recherche INRIA Sophia-Antipolis, 2004 route des Lucioles, BP 93, 06902 SOPHIA-ANTIPOLIS Cedex

---

Éditeur  
INRIA, Domaine de Voluceau, Rocquencourt, BP 105, 78153 LE CHESNAY Cedex (France)  
ISSN 0249-6399