Int4Sci :
Scilab Interface for Interval Analysis

http://www-sop.inria.fr/coprin/logiciels/Int4Sci/

David.Daney@inria.fr

Project Team Coprin
INRIA Sophia Antipolis-Méditerranée

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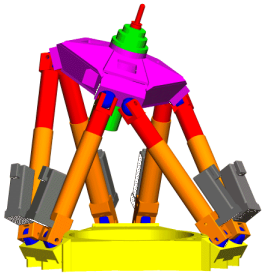
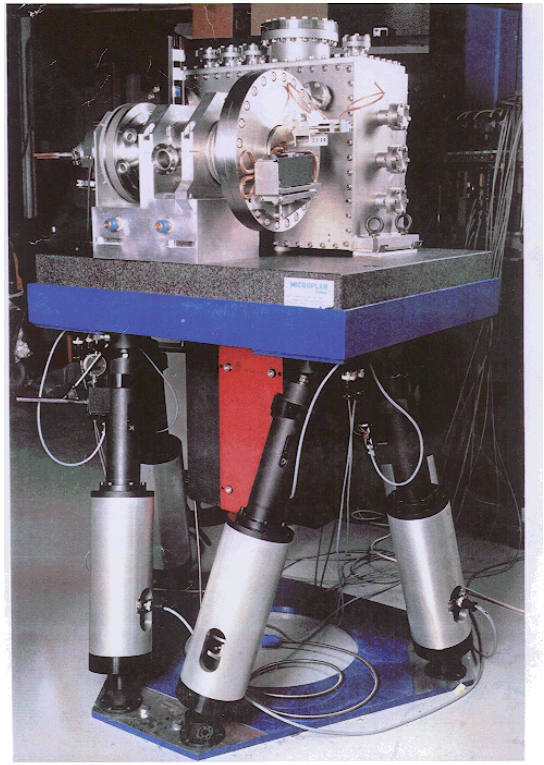
SCAN 2010, Lyon, France

Team Coprin: Robotics and ...

Parallel Manipulator





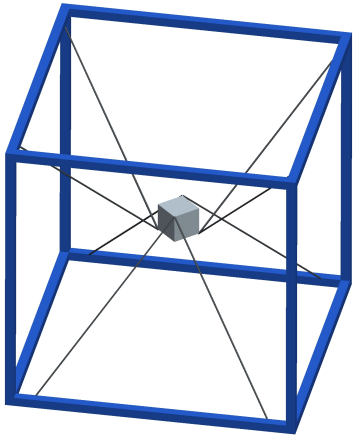
ESRF, Accurate
positioning manipulator

CMW
LGV milling machine

Crane based on a cable driven robot

Crane rescue

Wrench-Feasible Workspace of Parallel Cable Driven Mechanisms

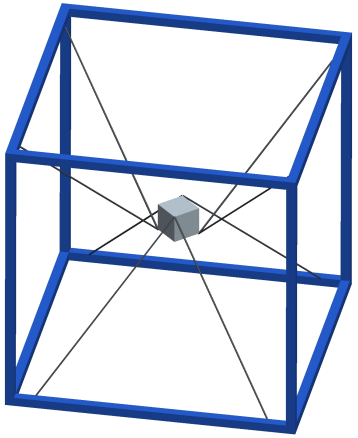


- X, position and orientation (n dof)
  the interval vector (box) $[\mathbf{X}] = [\underline{\mathbf{X}}, \overline{\mathbf{X}}]$
  a set of poses $\{\mathbf{X} | \underline{\mathbf{X}} \leq \mathbf{X} \leq \overline{\mathbf{X}}\}$
- τ_i, Tension in $i = 1, \ldots, m$ cables
  the box $[\tau]$ Set of allowed tensions in the cables:
  $\{\tau \ | \ \tau_i \in [\tau_{i_{min}} > 0, \tau_{i_{max}}], \ \forall\, 1 \leq i \leq m\}$
- f, Total wrench exerted by the cables at C
  the box $[\mathbf{f}]$ the set of wrenches (forces and moments)
  to be applied by the cables on the mobile platform

Static relation

$W_{n \times m} \tau = f$, with the wrench matrix $W(X) = -J^{-T}(X)$

Wrench-Feasible Workspace of Parallel Cable Driven Mechanisms



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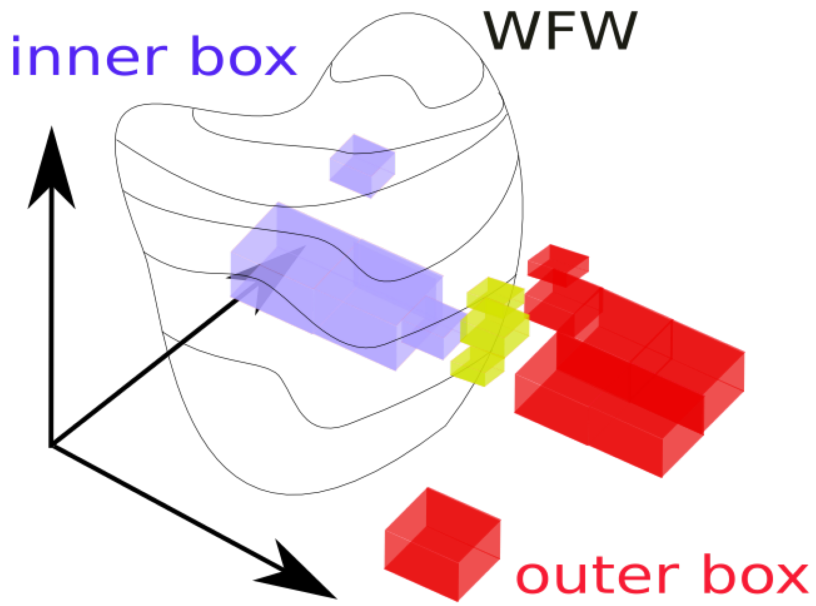
The Wrench-Feasible Workspace (WFW)
the set of robot poses for which the cable tensions allow to generated a given set of wrenches.

$$\text{WFW} \equiv \{X \ | \ \forall \, f \in [\mathbf{f}], \exists \, \tau \in [\tau] \text{ such that } W(X)\tau = f\}$$

Wrench-Feasible Workspace of Parallel Wire Driven Mechanisms



Algo: Branch and prune on $[\mathbf{X}]$

- Initial box $[\mathbf{X}]_1$

for $\mathcal{X} = [\mathbf{X}]_1, \ldots, [\mathbf{X}]_i, \ldots$

if $[\mathbf{X}] \cap WFW = \emptyset$, Outer box

if $[\mathbf{X}] \subset WFW$, Inner box

else bisection of $[\mathbf{X}] = [\mathbf{X}_{inf}] \cup [\mathbf{X}_{sup}]$,
$\mathcal{X} \leftarrow \mathcal{X}, [\mathbf{X}_{inf}], [\mathbf{X}_{sup}]$

Wrench-Feasible Workspace of Parallel Wire Driven Mechanisms

Outer Boxes

$[\mathbf{X}]$ lies fully outside the WFW **if** sufficient conditions (but not necessary)

First Test: $[\mathbf{f}] \not\subset [\mathbf{W}][\tau]$;

Stronger Test: $\forall\, \tau \in [\tau], W\tau \neq f_y$ with f_y the set of vertices of the box $[\mathbf{f}]$

Consistency
techniques

Inner Boxes …

Wrench-Feasible Workspace of Parallel Cable Driven Mechanisms

Inner Boxes

$[\mathbf{X}]$ lies fully inside the WFW **if** A sufficient condition (but not necessary)
$\forall\, W \in [\mathbf{W}], \forall\, f \in [\mathbf{f}], \exists\, \tau \in [\tau]$ such that $W\tau = f$

[Rohn2002]

The system of interval linear equations $[\mathbf{W}]\tau = [\mathbf{f}]$ *is strongly feasible if and only if the* 2^n *systems of linear equations* $\mathbf{W_y}\tau = \mathbf{f_y}$ *are feasible*

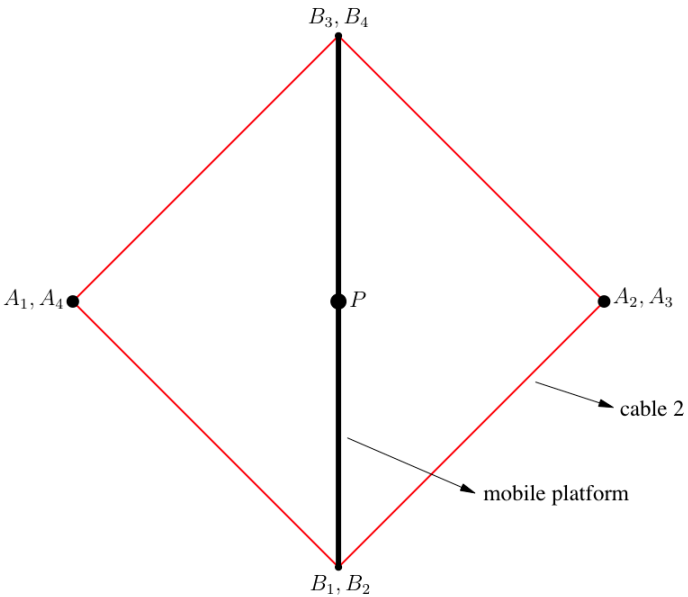
$\mathbf{W_y}, \mathbf{f_y}$ are a selection of 2^n *extreme systems* ($\mathbf{W_y}_{i,j} = \overline{W_{i,j}} or \underline{W_{i,j}}$; $f_{y_i} = \overline{f_i}$ or $\underline{f_i}$)

Feasibility of linear systems :
Linear Programing approach

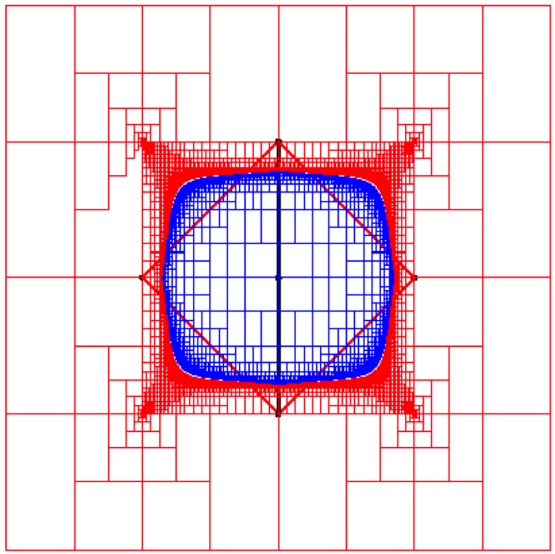
$\min c^T\tau$ subject to $\mathbf{W_y}\tau = \mathbf{f_y}, \tau \in [\tau]$ (with $c = 0$)

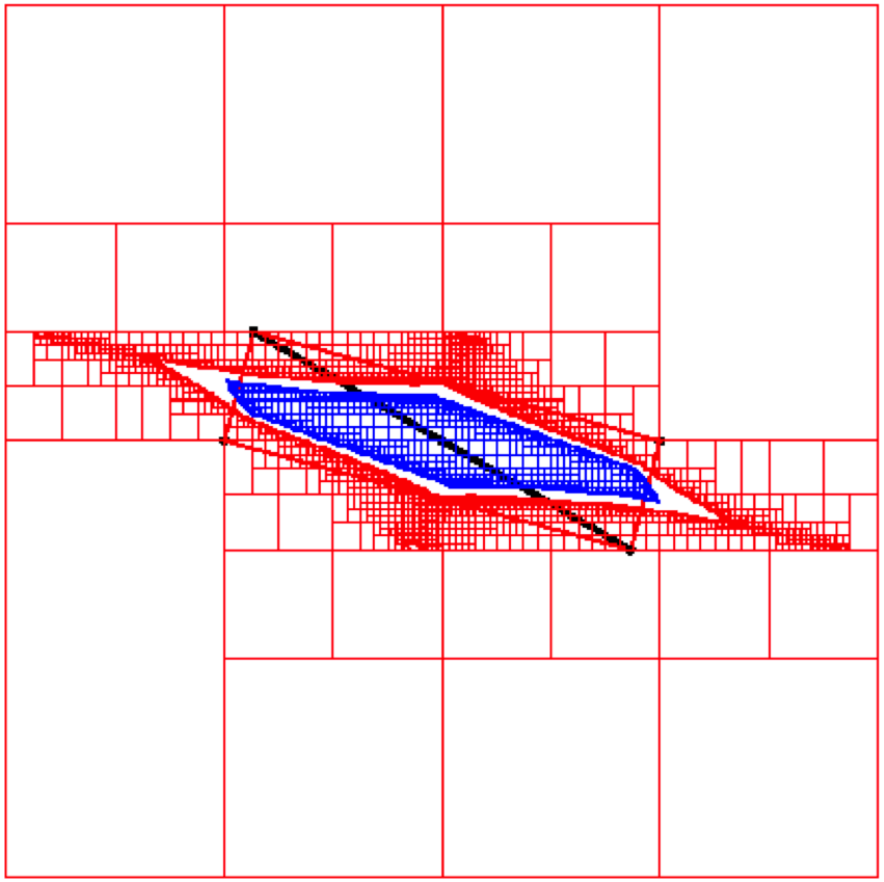
Examples: WFW

Planar 3-DOF Mechanism



- Tensions $[\tau_{1,..,4}] = [1, 54]$ (N)
- $[\mathbf{f}] = ([-10, 10], [-10, 10], [-0.5, 0.5])^T$ (N,N,N.m)
- $\phi = 0^o$, $\phi = 60^o$

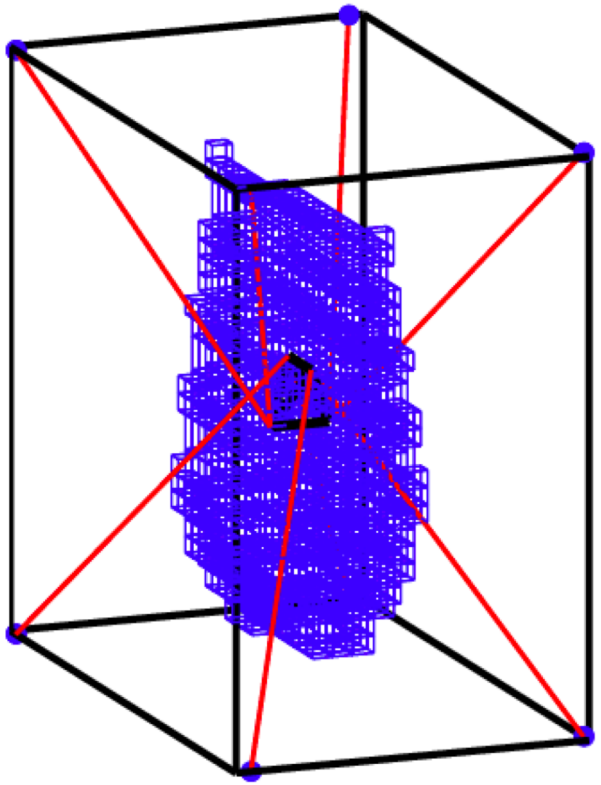




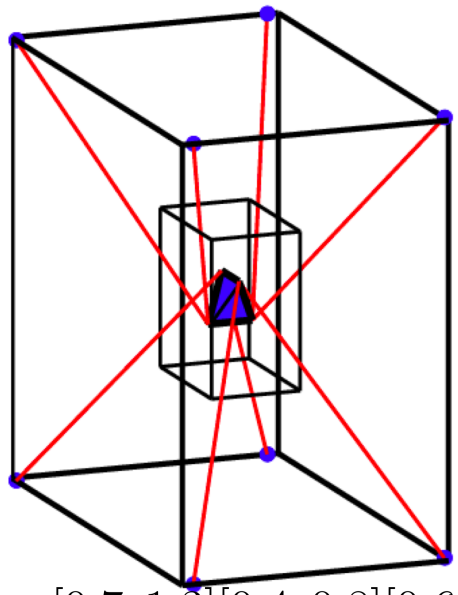
Examples: WFW

6-DOF parallel Mechanism driven by 8 wires

- Mobile platform : regular tetrahedron 0.1 m
- $[\tau] = [1, 540]$ (N)
- $[\mathbf{f}] = [\ [-10, 10]^T_{3\times1}\ \ [-0.5, 0.5]^T_{3\times1}]^T$ (N),(N.m)
- $\forall$ euler's angles $[-\frac{-\pi}{12}, \frac{\pi}{12}], [-\frac{-\pi}{12}, \frac{\pi}{12}], [0, 0]$ (rad)

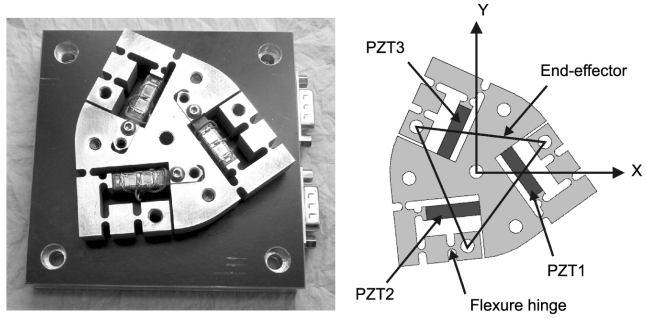


Full WFW in time = 970 s

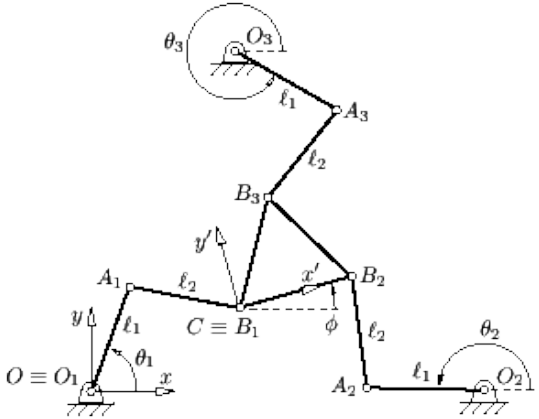


Box $[0.7, 1.3][0.4, 0.8][0.6, 1.3]$ (m)
guaranted in the WFW (41 s)

Examples: Geometrical workspace of a flexible 3RRR planar robot

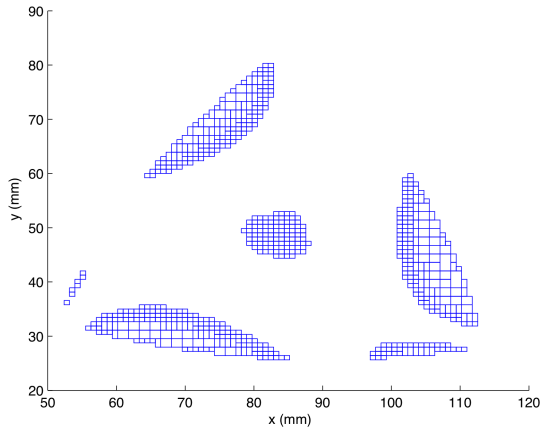


School of Mechanical Engineering, Univ. of Adelaide

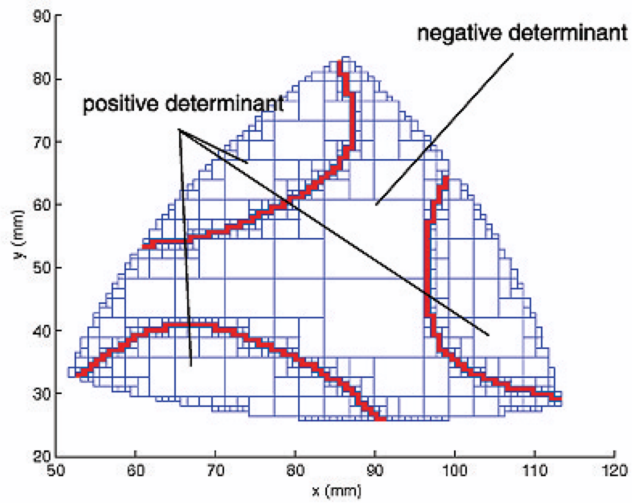


$$\mathrm{GW} \equiv \{X \mid IK(X) \in [\underline{\theta_i}, \overline{\theta_i}], \det(W(X)) \neq 0\}$$

Static relation $W(X)_{n\times n}\tau = f$



Basic computation of the determinant bounds



Using ALIAS Library test on test regularity

To promote Interval Techniques in robotics

Interval analysis is interested in robotics

Our contributions

- Robot Kinematics
- Verification of robot performances:
  Geometrical workspace, Determination of robot Singularities, Accuracy, Statics capabilities
- Design (taken into account mechanical tolerances)
- Calibration, Control …

Robotics problems

First investigations — Collaborations — Standard Tools

1997 → 2010

Team Coprin: Robotics and Interval Techniques

Origin of specialist members:
- 2 in robotics,
- 2 in constraints programming,
- 2 in applied mathematics

+ in Interval Techniques

1) Develop Interval Techniques (Interval Analysis + Constraint programming)
2) Applied to robotics

Libraries

1999 ALIAS www-sop.inria.fr/coprin/logiciels/ALIAS/ALIAS.html

Based on Bias/Profil IRC, Hamburg Univ. of Tech
http://www.ti3.tu-harburg.de/Software/PROFILEnglisch.html

User friendly toolkit for interval analysis methods diffusion

Aims

- To exemplify interval techniques
- To show the efficiency of these techniques
- To make them easily available

End-Users

- Students
- Non-experts in computer science
- Community researchers for prototyping

Wanted Properties

- Easy to install, to program
- To preserve the efficiency, IA capabilities
- To provide high level of IA functionalities
- To do not change user programming practices
- To do not reinvent the wheel

→ **Interface for Interval Analysis**

Interface for Interval Analysis

Some solutions

	Free	Symbolic	Interval Package
Matlab	✗	~	Intlab
Scilab	✓	~	Int4Sci
Octave	✓	~	
Pyton	✓	~	Pyinterval
Maple	✗	✓	intpakX Alias
Mathematica	✗	✓	Native Alias

Scilab Interface for Interval Analysis

- Matlab-like Open source
- Completeness functionalities (numerical tools, graphics) + add-ons
- Well known in academic and engineer community
- A quiet large number of users

- Supported by INRIA, R. Pereira engineer 2 years (2006-2007)

- Advanced type (overloading) → `mlist`
- Interface functionalities to create Interfaces to C, C++, Fortran
  Toolbox compilation process `tbx_build_tools`

Scilab progress …

Libraries linked

- Bias/Profil + Boost Interval tested in 2006
- Coprin advanced libraries : ALIAS
- others …

Int4Sci

2005 First prototype

2007 Int4Sci 1.0 (R. Pereira, D. Daney)

Interval type in Scilab %interM	Scilab 2.7
Arithmetic package	Bias
Interval linear solver package	Profil 2.0.4

Windows, Linux, MacOs

2010~11 Int4Sci 2.0 (D. Daney, B. Neveu)

Interval type in Scilab %interM	Scilab 5.2.2
Arithmetic package	Bias
Interval linear solver package	Profil 2.0.8
Interval Polynomial package %interP	Scilab 5.2.2 + Alias
Interval Solver package	Alias

Windows, Linux, MacOs

Interval type in Scilab : `mlist %interM`

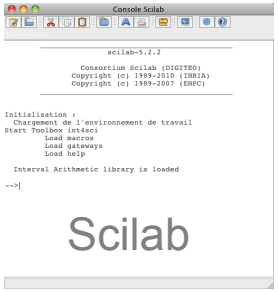
Scilab mlist : %interM

```
x=mlist(["interM","dims",  "inf","sup","arith",    "mode"],
                  size(a), a,    b,   "classical","double");
```

```
-->z=interval(-2,5)
 z  =

 |-2,5|

--> M=#(rand(3,3),rand(3,3));
--> M(2:3,2:3)=[sum(M(2:3,:),'c') prod(M(2:3,:),'c')]
```

%interM_p(x)
%interM_i_interM
%interM_sum
…

Int4Sci Interface



Macros
Scilab

Gateway
C

Interface
C, C++, Frotran

Library

"Add" example

```
-->  #(1,2) + #(-3,1)
```

```
c=%interM_s_interM(a,b)

[c.inf,c.sup,flag] = scioperator
(a.inf,a.sup,'a',b.inf,b.sup);
```

```
Int  intoperator (char *fname)
```

```
Int   operate (const double *ainf …
```

```
VOID BiasAddII (BIASINTERVAL *…
```

Files

- builder.sce
- macros
  - buildermacros.sce
  - intervaloperator.sci
- sci_gateway
  - builder_gateway.sce
  - c
    - builder_gateway_c.sce
    - intervaloperator.sci
- src
  - builder_src.sce
  - c
    - builder_c.sce
    - Biasoperator.c

Interval extended arithmetics

```
-->t=#(-1,2)+#(-4,5)
 t  =

 |-5,7|

-->log(#(-10,10))
 ans  =

 |-Inf,2.3025851|
```

+, -, x, \, exp, log, ^, sin, cos …

Interval Functions

```
-->#(-10,10):2
 ans  =

     ans(1)
 |-10,0|

      ans(2)
 |0,10|
```

mid, rad, inf, sup
Intersection, :2 , hull …

Interval linear solver package

```
-->A = #([4,-1,1.5;-0.5,-7,1;-1.5,-0.7,2],[5,1,2.5;.5,-5,2;-.5,-.5,3]);
-->b = #([3;0;3],[4;2;4]);
-->x = A\b;
-->x = I4Slinearsolve(A,b,"GE");
-->x = I4Slinearsolve(A,b,"PHB");
x  =

!|-1.0604173,1.3836696|  !
!                        !
!|-0.7446036,1.3320011|  !
!                        !
!|0.7583502,2.9840853|   !

-->x = I4Slinearsolve(A,b,x,"GS",10,0.89)
 x  =

!|-1.0604173,1.048619|   !
!                        !
!|-0.3543717,1.2996759|  !
!                        !
!|0.7583502,2.9840853|   !
```

Interval polynomials package

```
-->p1 = intpoly([#(1,2),#(-5,2),#(0,2)])
 p1  =

 |-8,20|+|-18,12|*ix+|-6,4|*ix^2+|1,1|*ix^3

-->p2 = intpoly([#(1,2),#(-5,2),#(0,2)],"x","coeff")
 p2  =

 |1,2|+|-5,2|*x+|0,2|*x^2

-->s = poly(0,'s');

-->a = [#(1,2)*s^5, #(1,2)+#(2)*s^2; 2+3*s,s^3]
 a  =

 |1,2|*s^5                          |1,2|+|2,2|*s^2

 |2,2|+|3,3|*s                      |1,1|*s^3


-->polyeval(a,[2,#(-%inf,2);#(1,2),0])
 ans  =


!|32,64|  |-Inf,Inf|  !
!                     !
!|5,8|    |0,0|       !
```

Int4Sci 2.0 Installation

Install Libraries
- Scilab 5.2.2
- Profil/Bias (2.0.8)
    * Arithmetics
    * Intrv. Linear. Solve
- Alias
    * Intrv. Polynomial package

In Scilab

--> `exec builder.sce`

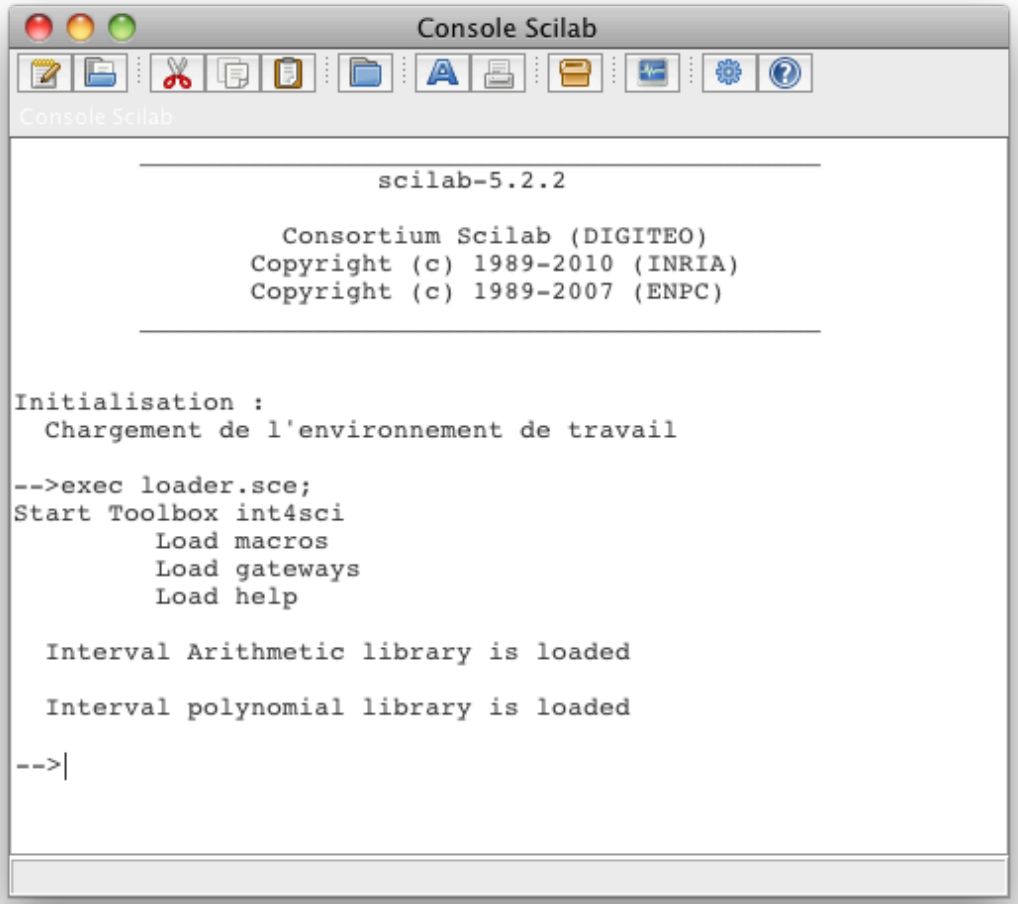
Console Scilab

```
                    scilab-5.2.2

                Consortium Scilab (DIGITEO)
            Copyright (c) 1989-2010 (INRIA)
            Copyright (c) 1989-2007 (ENPC)


Initialisation :
  Chargement de l'environnement de travail

-->exec builder.sce;
Building macros...
-- Création de [int4scilib] (Macros) --
Building sources...
   Génère un fichier loader
   Génère un Makefile
   ilib_gen_Make : Copie les fichiers de compilation (Makefile*, libtool...) vers TMPDIR
   ilib_gen_Make : Copie Biasoperator.c vers TMPDIR
   ilib_gen_Make : configure : Génère le Makefile.
   ilib_gen_Make : Modification du Makefile dans TMPDIR.
   Exécute le Makefile
   Génère un fichier cleaner
   Génère un fichier loader
   Génère un Makefile
   ilib_gen_Make : Copie les fichiers de compilation (Makefile*, libtool...) vers TMPDIR
   ilib_gen_Make : Copie Profilpoly.cpp vers TMPDIR
   ilib_gen_Make : Copie ProfilILSR.cpp vers TMPDIR
   ilib_gen_Make : configure : Génère le Makefile.
   ilib_gen_Make : Modification du Makefile dans TMPDIR.
   Exécute le Makefile
   Génère un fichier cleaner
Building gateway...
   Génère un fichier gateway
   Génère un fichier loader
   Génère un Makefile
   ilib_gen_Make : Copie les fichiers de compilation (Makefile*, libtool...) vers TMPDIR
   ilib_gen_Make : Copie intoperator.c vers TMPDIR
   ilib_gen_Make : Copie intILSR.c vers TMPDIR
   ilib_gen_Make : Copie intpoly.c vers TMPDIR
   ilib_gen_Make : Copie libint4sci.c vers TMPDIR
   ilib_gen_Make : configure : Génère le Makefile.
   ilib_gen_Make : Modification du Makefile dans TMPDIR.
   Exécute le makefile
   Génère un fichier cleaner
Generating loader_gateway.sce...
Generating cleaner_gateway.sce...
Génération de loader.sce...
Generating cleaner.sce...

--> |
```

Int4Sci 2.0 loader

In Scilab

```
--> exec loader.sce
```



A small DEMO …

Challenges and “what is at stake”

✚ Increase high level functionalities
→ therefore users and developers interest for Int4Sci

✚ A perennial long lasting development and technical support Int4sci

- Increase the contributions of external teams/projects

✚ Manage the dependency of Int4sci to external libraries

- Ensure the good functioning and linking of low level libraries
- Interoperability and interchanging of low level libraries

✚ Interface Ergonomics

Conclusion

- Int4Sci: a Scilab interface for interval Analysis
- End-Users: Students and Non experts (engineers, researchers)
- Aims: get a simple access to
  - basic functionalities
  - Link **your** advanced functionalities,
  - Prototyping

Road map

- release 2.0 (improve installation and Make binaries available)
- **Contribute ….**