CddInterface

Gap interface to Cdd package

0.1

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Chapter 1

Introduction

1.1 Why CddInterface

We know that every convex polyhedron has two representations, one as the intersection of finite half-spaces and the other as Minkowski sum of the convex hull of finite points and the nonnegative hull of finite directions. These are called H-representation and V-representation, respectively.
CddInterface is basicly written to translate between these two representations.

1.2 H-representation and V-representation of polyhedra

Let us start by introducing the H-representation. Let A be $m \times d$ matrix and let b be a column m-vector. The H-representation of the polyhedron defined by the system $b + Ax \geq 0$ of m inequalities and d variables $x = (x_1, \ldots, x_d)$ is as follows:
H-representation
linearity $t,\ [i_1, i_2, \ldots, i_t]$
begin
$m \times (d+1)$ numbertype
$b \qquad A$
end
The linearity line is added when we want to specify that some rows of the system $b + Ax$ are equalities. That is, $k \in \{i_1, i_2, \ldots, i_t\}$ means that the row k of the system $b + Ax$ is specified to be equality. For example, the H-representation of the polyhedron defined by the following system:
$4 - 3x_1 + 6x_2 - 5x_4 = 0$
$1 + 2x_1 - 2x_2 - 7x_3 \geq 0$
$-3x_2 + 5x_4 = 0$
is as follows:
H-representation
linearity $2,\ [1, 3]$
begin
3×5 rational

4	-3	6	0	-5
1	2	-2	-7	0
0	0	-3	0	5

end

Next we define Polyhedra V-format. Let P be represented by n gerating points and s generating directions (rays) as

$$P = conv(v_1,\dots,v_n) + nonneg(r_{n+1},\dots,r_{n+s}).$$

Then the Polyhedra V-format is for P is:

V-representation
linearity $t,\ \ [i_1,i_2,\dots,i_t]$
begin
$(n+s)\times(d+1)$ numbertype
1 v_1
$\vdots$ $\vdots$
1 v_n
0 r_{n+1}
$\vdots$ $\vdots$
0 r_{n+s}
end

In the above format the generating points and generating rays may appear mixed in arbitrary order. Linearity for V-representation specifies a subset of generators whose coefficients are relaxed to be free. That is, $k \in \{i_1,i_2,...,i_t\}$ specifies that the k-th generator is specified to be free. This means for each such a ray r_k , the line generated by r_k is in the polyhedron, and for each such a vertex v_k , its coefficient is no longer nonnegative but still the coefficients for all v_i's must sum up to one.
For example the V-representation of the polyhedron defined as

$$P := conv((2,3),(-2,-3),(3,5)) + nonneg(\ (1,2),(-1,-2),(2,11)\ )$$

V-representation
linearity $2,\ \ [1,3]$
begin
4×3 numbertype

1	2	3
1	3	5
0	1	2
0	2	11

end

Chapter 2

Creating polyhedra and their Operations

2.1 Creating a polyhedron

2.1.1 Cdd_PolyhedronByInequalities

▷ `Cdd_PolyhedronByInequalities(`*arg*`)` (function)

Returns: a `CddPolyhedron` Object

The function takes a list in which every entry represents an inequality(or equality). In case we want some entries to represent equalities we should refer in a second list to their indices.

Example

```
gap> A:= Cdd_PolyhedronByInequalities( [ [ 0, 1, 0 ], [ 0, 1, -1 ] ] );
< Polyhedron given by its H-representation >
gap> Display( A );
H-representation
begin
   2 X 3  rational

   0   1   0
   0   1  -1
end
gap> B:= Cdd_PolyhedronByInequalities( [ [ 0, 1, 0 ], [ 0, 1, -1 ] ], [ 2 ] );
< Polyhedron given by its H-representation >
gap> Display( B );
H-representation
Linearity 1, [ 2 ]
begin
   2 X 3  rational

   0   1   0
   0   1  -1
end
```

2.1.2 Cdd_PolyhedronByGenerators

▷ `Cdd_PolyhedronByGenerators(`*arg*`)` (function)

Returns: a `CddPolyhedron` Object

The function takes a list in which every entry represents a vertex in the ambient vector space. In case we want some vertices to be free(the vertex and its negative belong to the polyhedron) we should refer in a second list to their indices .

Example
```
gap> A:= Cdd_PolyhedronByGenerators( [ [ 0, 1, 3 ], [ 1, 4, 5 ] ] );
< Polyhedron given by its V-representation >
gap> Display( A );
V-representation
begin
   2 X 3  rational

   0  1  3
   1  4  5
end
gap> B:= Cdd_PolyhedronByGenerators( [ [ 0, 1, 3 ] ], [ 1 ] );
< Polyhedron given by its V-representation >
gap> Display( B );
V-representation
Linearity 1, [ 1 ]
begin
   1 X 3  rational

   0  1  3
end
```

2.2 Some operations on polyhedra

2.2.1 Cdd_Canonicalize (for IsCddPolyhedron)

▷ `Cdd_Canonicalize(`*poly*`)` (operation)

Returns: a `CddPolyhedron` Object

The function takes a polyhedron and reduces its defining inequalities (generators set) by deleting all redundant inequalities (generators).

Example
```
gap> A:= Cdd_PolyhedronByInequalities( [ [ 0, 2, 6 ], [ 0, 1, 3 ], [1, 4, 10 ] ] );
< Polyhedron given by its H-representation >
gap> B:= Cdd_Canonicalize( A );
< Polyhedron given by its H-representation >
gap> Display( B );
H-representation
begin
   2 X 3  rational

   0   1   3
   1   4  10
end
```

2.2.2 Cdd_V_Rep (for IsCddPolyhedron)

▷ `Cdd_V_Rep(`*poly*`)` (operation)

Returns: a `CddPolyhedron` Object

The function takes a polyhedron and returns its reduced V-representation.

2.2.3 Cdd_H_Rep (for IsCddPolyhedron)

▷ `Cdd_H_Rep(poly)` (operation)

Returns: a `CddPolyhedron` Object

The function takes a polyhedron and returns its reduced H-representation.

Example
```
gap> A:= Cdd_PolyhedronByInequalities( [ [ 0, 1, 1 ], [0, 5, 5 ] ] );
 Polyhedron given by its H-representation >
gap> B:= Cdd_V_Rep( A );
< Polyhedron given by its V-representation >
gap> Display( B );
V-representation
Linearity 1, [ 2 ]
begin
   2 X 3  rational

   0   1   0
   0  -1   1
end
gap> C:= Cdd_H_Rep( B );
< Polyhedron given by its H-representation >
gap> Display( C );
H-representation
begin
   1 X 3  rational

   0  1  1
end
gap> D:= Cdd_PolyhedronByInequalities( [ [ 0, 1, 1, 34, 22, 43 ],
> [ 11, 2, 2, 54, 53, 221 ], [33, 23, 45, 2, 40, 11 ] ] );
< Polyhedron given by its H-representation >
gap> Cdd_V_Rep( D );
< Polyhedron given by its V-representation >
gap> Display( last );
V-representation
Linearity 2, [ 5, 6 ]
begin
   6 X 6  rational

   1  -743/14   369/14    11/14         0         0
   0    -1213      619       22         0         0
   0       -1        1        0         0         0
   0      764     -390      -11         0         0
   0   -13526     6772       99       154         0
   0  -116608    59496     1485         0       154
end
```

2.2.4 Cdd_FourierProjection (for IsCddPolyhedron, IsInt)

▷ `Cdd_FourierProjection(poly, i)` (operation)

Returns: a `CddPolyhedron` Object

The function returns the Fourier projection of the polyhedron in the subspace $(O,x_1,\dots,x_{i-1},x_{i+1},\dots,x_n)$ after applying the Fourier elemination algorithm to get rid of the variable x_i.

To illustrate this projection, Let $P = Conv((1,2),(4,5))$ in $\mathbb{Q}^2$.
To find its projection on the subspace (O,x_1), we apply the Fourier elemination to get rid of x_2

Example
```
gap> P:= Cdd_PolyhedronByGenerators( [ [ 1, 1, 2 ], [ 1, 4, 5 ] ] );
< Polyhedron given by its H-representation >
gap> H:= Cdd_H_Rep( P );
< Polyhedron given by its H-representation >
gap> Display( H );
H-representation
Linearity 1, [ 1 ]
begin
   3 X 3  rational

   -1  -1   1
    4  -1   0
   -1   1   0
end
gap> P_x1:= Cdd_FourierProjection( H, 2);
< Polyhedron given by its H-representation >
gap> Display( P_x1 );
H-representation
Linearity 1, [ 3 ]
begin
   3 X 3  rational

    4  -1   0
   -1   1   0
    0   0   1
end
gap> Display( Cdd_V_Rep( P_x1 ) );
V-representation
begin
   2 X 3  rational

   1  1  0
   1  4  0
end
```

Let again $Q = Conv((2,3,4),(2,4,5)) + nonneg((1,1,1))$, and let us compute its projection on (O,x_2,x_3)

Example
```
gap>  Q:= Cdd_PolyhedronByGenerators( [ [1,2,3,4],[1,2,4,5], [0,1,1,1] ] );
< Polyhedron given by its V-representation >
gap>  R:= Cdd_H_Rep( Q );
< Polyhedron given by its H-representation >
```

```
gap>  Display( R );
H-representation
Linearity 1, [ 1 ]
begin
   4 X 4  rational

   -1   0  -1   1
    2   1  -1   0
   -2   1   0   0
   -1  -1   1   0
end
gap>  P_x2_x3:= Cdd_FourierProjection( R, 1);
< Polyhedron given by its H-representation >
gap>  Display( P_x2_x3 );
H-representation
Linearity 2, [ 1, 3 ]
begin
   3 X 4  rational

   -1   0  -1   1
   -3   0   1   0
    0   1   0   0
end
gap>  Display( Cdd_V_Rep( last ) ) ;
V-representation
begin
   2 X 4  rational

   0  0  1  1
   1  0  3  4
end
```

Chapter 3

Linear Programs

3.1 Creating and solving linear programs

3.1.1 Cdd_LinearProgram (for IsCddPolyhedron, IsString, IsList)

▷ `Cdd_LinearProgram(poly, str, obj)` (operation)

Returns: a `CddLinearProgram` Object

The function takes three variables. The first is a polyhedron `poly`, the second `str` should be max or min and the third `obj` is the objective.

3.1.2 Cdd_SolveLinearProgram (for IsCddLinearProgram)

▷ `Cdd_SolveLinearProgram(lp)` (operation)

Returns: a list if the program is optimal, otherwise returns the value 0

The function takes a linear program. If the program is optimal, the function returns a list of two entries: the solution vector and the optimal value of the objective, otherwise it returns the value 0.

To illustrate the using of these functions, let us solve the linear program given by: **Maximize** $P(x,y) = 1 - 2x + 5y$, with
$100 \leq x \leq 200$
$80 \leq y \leq 170$
$y \geq -x + 200$

We bring the inequalities to the form $b + AX \geq 0$, we get:
$-100 + x \geq 0$
$200 - x \geq 0$
$-80 + y \geq 0$
$170 - y \geq 0$
$-200 + x + y \geq 0$

Example
```
gap> A:= Cdd_PolyhedronByInequalities( [ [ -100, 1, 0 ], [ 200, -1, 0 ],
> [ -80, 0, 1 ], [ 170, 0, -1 ], [ -200, 1, 1 ] ] );
< Polyhedron given by its H-representation >
gap> Lp:= Cdd_LinearProgram( A, "max", [1, -2, 5 ] );
< Linear program >
```

```
gap> S:= Cdd_SolveLinearProgram( Lp );
[ [ 100, 170 ], 651 ]
gap> B:= Cdd_V_Rep( A );
< Polyhedron given by its V-representation >
gap> Display( Lp );
Linear program given by:
H-representation
begin
   5 X 3  rational

   -100     1     0
    200    -1     0
    -80     0     1
    170     0    -1
   -200     1     1
end
max  [ 1, -2, 5 ]
gap> Display( B );
V-representation
begin
   5 X 3  rational

   1  100  170
   1  100  100
   1  120   80
   1  200   80
   1  200  170
end
```

So the optimal solution is $(x = 100, y = 170)$ with optimal value $p = 1 - 2(100) + 5(170) = 651$.

Chapter 4

Attributes and properties

4.1 Attributes and properties of polyhedron

4.1.1 Cdd_Dimension (for IsCddPolyhedron)

▷ `Cdd_Dimension(`*poly*`)` (attribute)

Returns: The dimension of the polyhedron

4.1.2 Cdd_AmbientSpaceDimension (for IsCddPolyhedron)

▷ `Cdd_AmbientSpaceDimension(`*poly*`)` (attribute)

Returns: The dimension of the ambient space of the polyhedron

4.1.3 Cdd_GeneratingVertices (for IsCddPolyhedron)

▷ `Cdd_GeneratingVertices(`*poly*`)` (attribute)

Returns: The reduced generating vertices of the polyhedron

4.1.4 Cdd_GeneratingRays (for IsCddPolyhedron)

▷ `Cdd_GeneratingRays(`*poly*`)` (attribute)

Returns: The reduced generating rays of the polyhedron

4.1.5 Cdd_Equalities (for IsCddPolyhedron)

▷ `Cdd_Equalities(`*poly*`)` (attribute)

Returns: The reduced defining equalities of the polyhedron

4.1.6 Cdd_Inequalities (for IsCddPolyhedron)

▷ `Cdd_Inequalities(`*poly*`)` (attribute)

Returns: The reduced defining inequalities of the polyhedron

4.1.7 Cdd_InteriorPoint (for IsCddPolyhedron)

▷ `Cdd_InteriorPoint(`*poly*`)` (attribute)

Returns: An interior point of the polyhedron

4.1.8 Cdd_Faces (for IsCddPolyhedron)

▷ `Cdd_Faces(poly)` (attribute)

Returns: All faces with their dimensions

This function takes a H-represented polyhedron `poly` and returns a list. Every entry in this list is a again a list, contains the dimension and linearity of the face defined as a polyhedron over the same system of inequalities.

4.1.9 Cdd_FacesWithInteriorPoints (for IsCddPolyhedron)

▷ `Cdd_FacesWithInteriorPoints(poly)` (attribute)

Returns: All faces with their dimensions and an interior point in each face

This function takes a H-represented polyhedron `poly` and returns a list. Every entry in this list is a again a list, contains the dimension, linearity of the face defined as a polyhedron over the same system of inequalities and an interior point in the face.

4.1.10 Cdd_Facets (for IsCddPolyhedron)

▷ `Cdd_Facets(poly)` (attribute)

Returns: All facets with their dimensions

This function takes a H-represented polyhedron `poly` and returns a list. Every entry in this list is a again a list, contains the dimension, linearity of the facet defined as a polyhedron over the same system of inequalities.

4.1.11 Cdd_FacetsWithInteriorPoints (for IsCddPolyhedron)

▷ `Cdd_FacetsWithInteriorPoints(poly)` (attribute)

Returns: All faces with their dimensions and an interior point in each face

This function takes a H-represented polyhedron `poly` and returns a list. Every entry in this list is a again a list, contains the dimension, linearity of the facet defined as a polyhedron over the same system of inequalities and an interior point in the facet.

4.1.12 Cdd_IsEmpty (for IsCddPolyhedron)

▷ `Cdd_IsEmpty(poly)` (property)

Returns: `true` if the polyhedron is empty and `false` otherwise

4.1.13 Cdd_IsCone (for IsCddPolyhedron)

▷ `Cdd_IsCone(poly)` (property)

Returns: `true` if the polyhedron is cone and `false` otherwise

4.1.14 Cdd_IsPointed (for IsCddPolyhedron)

▷ `Cdd_IsPointed(poly)` (property)

Returns: `true` if the polyhedron is pointed and `false` otherwise

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