

ipopt

July 23, 2025

This file is part of CasADi.

CasADi -- A symbolic framework for dynamic optimization.
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1 nlpsol

```
[1]: from casadi import *  
     from numpy import *
```

In this example, we will solve a few optimization problems with increasing complexity

2 Scalar unconstrained problem

$\min_x (x - 1)^2 \setminus \text{subject to } -10 \leq x \leq 10 \setminus$
with x scalar

```
[2]: x= SX.sym('x')  
     nlp = {'x':x, 'f':(x-1)**2}
```

```
[3]: solver = nlpsol('solver', 'ipopt', nlp)
sol = solver(lbx=-10, ubx=10)
```

```
*****
This program contains Ipopt, a library for large-scale nonlinear optimization.
Ipopt is released as open source code under the Eclipse Public License (EPL).
For more information visit https://github.com/coin-or/Ipopt
*****
```

This is Ipopt version 3.14.11, running with linear solver MUMPS 5.4.1.

```
Number of nonzeros in equality constraint Jacobian...:      0
Number of nonzeros in inequality constraint Jacobian.:      0
Number of nonzeros in Lagrangian Hessian...:           1
```

```
Total number of variables...:      1
      variables with only lower bounds:      0
      variables with lower and upper bounds:    1
      variables with only upper bounds:      0
```

```
Total number of equality constraints...:      0
Total number of inequality constraints...:      0
      inequality constraints with only lower bounds:      0
      inequality constraints with lower and upper bounds:    0
      inequality constraints with only upper bounds:      0
```

iter	objective	inf_pr	inf_du	lg(mu)	d	lg(rg)	alpha_du	alpha_pr	ls
0	1.0000000e+00	0.00e+00	2.00e+00	-1.0	0.00e+00	-	0.00e+00	0.00e+00	0
1	8.2644627e-03	0.00e+00	1.53e-02	-1.0	9.09e-01	-	9.16e-01	1.00e+00f	1
2	3.3212748e-06	0.00e+00	2.08e-17	-1.0	8.91e-02	-	1.00e+00	1.00e+00f	1
3	9.3171258e-10	0.00e+00	7.11e-17	-2.5	1.79e-03	-	1.00e+00	1.00e+00f	1
4	2.3111166e-12	0.00e+00	2.40e-17	-3.8	2.90e-05	-	1.00e+00	1.00e+00f	1
5	3.4736752e-16	0.00e+00	5.92e-17	-5.7	1.50e-06	-	1.00e+00	1.00e+00f	1
6	6.4072417e-22	0.00e+00	3.96e-17	-8.6	1.86e-08	-	1.00e+00	1.00e+00f	1

Number of Iterations...: 6

	(scaled)	(unscaled)
Objective...:	6.4072416740416713e-22	6.4072416740416713e-22
Dual infeasibility...:	3.9625445352197450e-17	3.9625445352197450e-17
Constraint violation...:	0.0000000000000000e+00	0.0000000000000000e+00
Variable bound violation:	0.0000000000000000e+00	0.0000000000000000e+00
Complementarity...:	2.5059073699316697e-09	2.5059073699316697e-09
Overall NLP error...:	2.5059073699316697e-09	2.5059073699316697e-09

Number of objective function evaluations = 7

```

Number of objective gradient evaluations      = 7
Number of equality constraint evaluations      = 0
Number of inequality constraint evaluations    = 0
Number of equality constraint Jacobian evaluations = 0
Number of inequality constraint Jacobian evaluations = 0
Number of Lagrangian Hessian evaluations      = 6
Total seconds in IPOPT                       = 0.004

```

EXIT: Optimal Solution Found.

	solver	:	t_proc	(avg)	t_wall	(avg)	n_eval
	nlp_f		84.00us	(12.00us)	21.12us	(3.02us)	7
	nlp_grad_f		928.00us	(116.00us)	19.04us	(2.38us)	8
	nlp_hess_l		41.00us	(6.83us)	10.60us	(1.77us)	6
	total		18.80ms	(18.80ms)	4.78ms	(4.78ms)	1

The solution is obviously 1:

```
[4]: print(sol['x'])
      assert(abs(sol['x']-1)<1e-9)
```

1

3 Constrained problem

$\min_x (x-1)^T \cdot (x-1) \setminus \text{subject to } -10 \leq x \leq 10 \setminus \text{subject to } 0 \leq x_1 + x_2 \leq 1 \setminus \text{subject to } x_0 = 2 \setminus$
 with $x \in \mathbf{R}^n$

```
[5]: n = 5
```

```
[6]: x=SX.sym('x',n)
```

Note how we do not distinguish between equalities and inequalities here

```
[7]: nlp = {'x':x, 'f':mtimes((x-1).T,x-1), 'g':vertcat(x[1]+x[2],x[0])}
```

```
[8]: solver = nlpsol('solver', 'ipopt', nlp)
      sol = solver(lbx=-10, ubx=10, lbg=[0,2], ubg=[1,2])
```

This is Ipopt version 3.14.11, running with linear solver MUMPS 5.4.1.

```

Number of nonzeros in equality constraint Jacobian...:      1
Number of nonzeros in inequality constraint Jacobian.:      2
Number of nonzeros in Lagrangian Hessian...:           5

Total number of variables...:      5
      variables with only lower bounds:      0
      variables with lower and upper bounds:      5

```

```

variables with only upper bounds:          0
Total number of equality constraints...:    1
Total number of inequality constraints...:  1
    inequality constraints with only lower bounds:  0
    inequality constraints with lower and upper bounds:  1
    inequality constraints with only upper bounds:  0

iter   objective   inf_pr   inf_du lg(mu)  ||d|| lg(rg) alpha_du alpha_pr ls
  0   5.0000000e+00  2.00e+00  2.00e+00 -1.0  0.00e+00   -   0.00e+00  0.00e+00  0
  1   2.7716739e+00  0.00e+00  1.16e+00 -1.0  2.00e+00   -   3.75e-01  1.00e+00f  1
  2   1.5112117e+00  0.00e+00  4.53e-01 -1.0  1.31e+00   -   9.44e-01  6.62e-01f  1
  3   1.5183915e+00  0.00e+00  1.11e-16 -1.7  3.46e-02   -   1.00e+00  1.00e+00f  1
  4   1.5009100e+00  0.00e+00  2.03e-04 -3.8  1.73e-02   -   9.88e-01  1.00e+00f  1
  5   1.5000028e+00  0.00e+00  2.22e-16 -5.7  9.07e-04   -   1.00e+00  1.00e+00f  1
  6   1.5000000e+00  0.00e+00  2.04e-16 -8.6  2.85e-06   -   1.00e+00  1.00e+00f  1

```

Number of Iterations...: 6

```

                                (scaled)                (unscaled)
Objective...:  1.4999999925191814e+00  1.4999999925191814e+00
Dual infeasibility...:  2.0424918385704731e-16  2.0424918385704731e-16
Constraint violation...:  0.0000000000000000e+00  0.0000000000000000e+00
Variable bound violation:  0.0000000000000000e+00  0.0000000000000000e+00
Complementarity...:  2.5191812953934411e-09  2.5191812953934411e-09
Overall NLP error...:  2.5191812953934411e-09  2.5191812953934411e-09

```

```

Number of objective function evaluations      = 7
Number of objective gradient evaluations      = 7
Number of equality constraint evaluations      = 7
Number of inequality constraint evaluations    = 7
Number of equality constraint Jacobian evaluations = 7
Number of inequality constraint Jacobian evaluations = 7
Number of Lagrangian Hessian evaluations     = 6
Total seconds in IPOPT                       = 0.004

```

EXIT: Optimal Solution Found.

```

solver :   t_proc      (avg)   t_wall      (avg)   n_eval
  nlp_f  |  57.00us ( 8.14us)  13.38us ( 1.91us)      7
  nlp_g  |  91.00us (13.00us)  20.60us ( 2.94us)      7
nlp_grad_f | 78.00us ( 9.75us)  17.95us ( 2.24us)      8
nlp_hess_l | 45.00us ( 7.50us)  10.64us ( 1.77us)      6
  nlp_jac_g | 50.00us ( 6.25us)  12.67us ( 1.58us)      8
  total  | 16.95ms (16.95ms)   4.26ms ( 4.26ms)      1

```

\$ 2 x_0 2\$ is not really as bad it looks. Ipopt will recognise this situation as an equality constraint.

The solution is obviously [2,0.5,0.5,1,1]:

```
[9]: print(sol['x'])
for (i,e) in zip(list(range(n)), [2,0.5,0.5,1,1]):
    assert(abs(sol['x'][i]-e)<1e-7)
```

[2, 0.5, 0.5, 1, 1]

4 Problem with parameters

$\min_x (x - a)^2 \setminus \text{subject to } -10 \leq x \leq 10 \setminus$

with x scalar

```
[10]: x=SX.sym('x')
a=SX.sym('a')
a_ = 2
nlp={'x':x, 'p':a, 'f':(x-a)**2}
```

```
[11]: solver = nlpsol('solver', 'ipopt', nlp)
sol = solver(lbx=-10, ubx=10, p=a_)
```

This is Ipopt version 3.14.11, running with linear solver MUMPS 5.4.1.

```
Number of nonzeros in equality constraint Jacobian...:      0
Number of nonzeros in inequality constraint Jacobian.:      0
Number of nonzeros in Lagrangian Hessian...:           1
```

```
Total number of variables...:      1
      variables with only lower bounds:      0
      variables with lower and upper bounds:    1
      variables with only upper bounds:      0
Total number of equality constraints...:      0
Total number of inequality constraints...:      0
      inequality constraints with only lower bounds:      0
      inequality constraints with lower and upper bounds:    0
      inequality constraints with only upper bounds:      0
```

iter	objective	inf_pr	inf_du	lg(mu)	d	lg(rg)	alpha_du	alpha_pr	ls
0	4.0000000e+00	0.00e+00	4.00e+00	-1.0	0.00e+00	-	0.00e+00	0.00e+00	0
1	3.3057851e-02	0.00e+00	5.64e-02	-1.0	1.82e+00	-	8.45e-01	1.00e+00f	1
2	2.8894889e-05	0.00e+00	1.53e-16	-1.0	1.76e-01	-	1.00e+00	1.00e+00f	1
3	4.4774726e-09	0.00e+00	1.08e-16	-2.5	5.31e-03	-	1.00e+00	1.00e+00f	1
4	9.8332283e-12	0.00e+00	2.02e-16	-3.8	6.38e-05	-	1.00e+00	1.00e+00f	1
5	1.4777036e-15	0.00e+00	3.79e-18	-5.7	3.10e-06	-	1.00e+00	1.00e+00f	1
6	2.7255842e-21	0.00e+00	1.26e-17	-8.6	3.84e-08	-	1.00e+00	1.00e+00f	1

Number of Iterations...: 6

(scaled)

(unscaled)

```

Objective...: 2.7255841628426173e-21 2.7255841628426173e-21
Dual infeasibility...: 1.2569571890559792e-17 1.2569571890559792e-17
Constraint violation...: 0.0000000000000000e+00 0.0000000000000000e+00
Variable bound violation: 0.0000000000000000e+00 0.0000000000000000e+00
Complementarity...: 2.5059124009153784e-09 2.5059124009153784e-09
Overall NLP error...: 2.5059124009153784e-09 2.5059124009153784e-09

```

```

Number of objective function evaluations      = 7
Number of objective gradient evaluations     = 7
Number of equality constraint evaluations     = 0
Number of inequality constraint evaluations   = 0
Number of equality constraint Jacobian evaluations = 0
Number of inequality constraint Jacobian evaluations = 0
Number of Lagrangian Hessian evaluations    = 6
Total seconds in IPOPT                      = 0.003

```

EXIT: Optimal Solution Found.

solver	:	t_proc	(avg)	t_wall	(avg)	n_eval
nlp_f		90.00us	(12.86us)	21.05us	(3.01us)	7
nlp_grad_f		68.00us	(8.50us)	15.97us	(2.00us)	8
nlp_hess_l		40.00us	(6.67us)	10.44us	(1.74us)	6
total		14.52ms	(14.52ms)	3.63ms	(3.63ms)	1

The solution is obviously a:

```
[12]: print(sol['x'])
      assert(abs(sol['x']-a_)<1e-9)
```

2

The parameter can change inbetween two solve calls:

```
[13]: sol = solver(lbx=-10, ubx=10, p=2*a_)
```

This is Ipopt version 3.14.11, running with linear solver MUMPS 5.4.1.

```

Number of nonzeros in equality constraint Jacobian...: 0
Number of nonzeros in inequality constraint Jacobian.: 0
Number of nonzeros in Lagrangian Hessian...: 1

Total number of variables...: 1
      variables with only lower bounds: 0
      variables with lower and upper bounds: 1
      variables with only upper bounds: 0
Total number of equality constraints...: 0
Total number of inequality constraints...: 0
      inequality constraints with only lower bounds: 0
      inequality constraints with lower and upper bounds: 0

```

inequality constraints with only upper bounds: 0

iter	objective	inf_pr	inf_du	lg(mu)	d	lg(rg)	alpha_du	alpha_pr	ls
0	1.6000000e+01	0.00e+00	8.00e+00	-1.0	0.00e+00	-	0.00e+00	0.00e+00	0
1	1.3223140e-01	0.00e+00	1.95e-01	-1.0	3.64e+00	-	7.31e-01	1.00e+00f	1
2	3.6066256e-04	0.00e+00	1.04e-16	-1.0	3.45e-01	-	1.00e+00	1.00e+00f	1
3	1.0362906e-06	0.00e+00	3.71e-16	-1.7	1.80e-02	-	1.00e+00	1.00e+00f	1
4	5.6293833e-11	0.00e+00	8.15e-17	-3.8	1.01e-03	-	1.00e+00	1.00e+00f	1
5	7.7214018e-15	0.00e+00	3.56e-16	-5.7	7.42e-06	-	1.00e+00	1.00e+00f	1
6	1.4239938e-20	0.00e+00	3.69e-16	-8.6	8.78e-08	-	1.00e+00	1.00e+00f	1

Number of Iterations...: 6

	(scaled)	(unscaled)
Objective...:	1.4239938056866796e-20	1.4239938056866796e-20
Dual infeasibility...:	3.6930385037381279e-16	3.6930385037381279e-16
Constraint violation...:	0.0000000000000000e+00	0.0000000000000000e+00
Variable bound violation:	0.0000000000000000e+00	0.0000000000000000e+00
Complementarity...:	2.5059305083202185e-09	2.5059305083202185e-09
Overall NLP error...:	2.5059305083202185e-09	2.5059305083202185e-09

Number of objective function evaluations	= 7
Number of objective gradient evaluations	= 7
Number of equality constraint evaluations	= 0
Number of inequality constraint evaluations	= 0
Number of equality constraint Jacobian evaluations	= 0
Number of inequality constraint Jacobian evaluations	= 0
Number of Lagrangian Hessian evaluations	= 6
Total seconds in IPOPT	= 0.005

EXIT: Optimal Solution Found.

	solver	:	t_proc	(avg)	t_wall	(avg)	n_eval
nlp_f		5.07ms	(723.86us)	22.35us	(3.19us)	7	
nlp_grad_f		63.00us	(7.88us)	15.23us	(1.90us)	8	
nlp_hess_l		41.00us	(6.83us)	9.84us	(1.64us)	6	
total		19.18ms	(19.18ms)	5.10ms	(5.10ms)	1	

The solution is obviously 2^*a :

```
[14]: print(sol['x'])
      assert(abs(sol['x']-2*a_)<1e-9)
```

4