```
#!/usr/bin/env python

import sys
sys.path.append(r"/Users/robertbrothers/Desktop/Fall 2014/Fundamentals_of_Robotics/robo_git/python/")
import robotics_functions as rf
import sympy as sy
import numpy as np


[a1,a2,a3,l1,l2,l3,d1,d2,d3,t1,t2,t3] = sy.symbols("a1,a2,a3,l1,l2,l3,d1,d2,d3,t1,t2,t3")
################## Problem 1 ############################
print "########### Problem 1 ##############################"
link_list = [
    [ 0, np.pi/2, 0, t1],
    [ 0,-np.pi/2,d2,  0],
    [l3, 0, 0, t3]
    ]

# a)
print "################## a) ###################################"
J_end = rf.symbolic_jacobian(link_list)
Je = J_end[0]
for i in range(len(J_end)-1):
  j = i+1
  Je = sy.Matrix.hstack(Je, J_end[j])
J_end = Je
sy.pprint(J_end)

# b)
print "########################## b) ################################"
speed = np.ones(len(link_list))
speed = np.hstack((speed, np.zeros(3)))
speed = sy.Matrix(speed).T
speed = J_end.T*speed
sy.pprint(speed)


############################################################


##################### Problem 2 ############################
print "####################### Problem 2 ########################"
link_list = [
    [ 0, 0, l1, t1],
    [l2, np.pi/2, 0, t2],
    [l3, 0, 0, t3]
    ]

# a) On paper - no function written for this yet

# b) jacobian of the end effector
J_end = rf.symbolic_jacobian(link_list)
sy.pprint(J_end)



############################################################


##################### Problem 3 ############################
print "########### Problem 3 ##########"
link_list = [
    [a1, 0, 0, t1],
    [a2, 0, 0, t2]
    ]

# a) On paper - no function written for this yet
# b) On paper - no function written for this yet
# c) On paper - no function written for this yet
```

```
########## Problem 1 ############################
################ a) ###################################
[1.0*d2*cos(t1) - 1.0*l3*sin(t1)*cos(t3) - 1.0*l3*sin(t3)*cos(t1)      1.0*sin(t1)
     -1.0*l3*sin(t1)*cos(t3) - 1.0*l3*sin(t3)*cos(t1)]
[                                                                              ]
[1.0*d2*sin(t1) - 1.0*l3*sin(t1)*sin(t3) + 1.0*l3*cos(t1)*cos(t3)      -1.0*cos(t1)
     -1.0*l3*sin(t1)*sin(t3) + 1.0*l3*cos(t1)*cos(t3)]
[                                                                              ]
[                                  0                                  6.12323399573677e
-17                          0                                     ]
[                                                                              ]
[                                  0                                           0
                            0                                     ]
[                                                                              ]
[                                  0                                           0
                            0                                     ]
[                                                                              ]
[                                 1.0                                          0
                           1.0                                    ]
########################### b) ###################################
[1.0*d2*sin(t1) + 1.0*d2*cos(t1) - 1.0*l3*sin(t1)*sin(t3) - 1.0*l3*sin(t1)*cos(t3) -
 1.0*l3*sin(t3)*cos(t1) + 1.0*l3*cos(t1)*cos(t3)]
[                                                                              ]
[                                                1.0*sin(t1) - 1.0*cos(t1) + 6.123233995736
77e-17                                                                         ]
[                                                                              ]
[                -1.0*l3*sin(t1)*sin(t3) - 1.0*l3*sin(t1)*cos(t3) - 1.0*l3*sin(t3)*c
os(t1) + 1.0*l3*cos(t1)*cos(t3)                                                ]
######################## Problem 2 ########################
[[-1.0*l2*sin(t1)*cos(t2) - 1.0*l2*sin(t2)*cos(t1) - 1.0*l3*(-6.12323399573677e-17*s
in(t1)*sin(t2) + 6.12323399573677e-17*cos(t1)*cos(t2))*sin(t3) - 1.0*l3*(1.0*sin(t1)
*cos(t2) + 1.0*sin(t2)*cos(t1))*cos(t3) ]
 [                                                                             ]
 [-1.0*l2*sin(t1)*sin(t2) + 1.0*l2*cos(t1)*cos(t2) + 1.0*l3*(-1.0*sin(t1)*sin(t2) +
1.0*cos(t1)*cos(t2))*cos(t3) + 1.0*l3*(-6.12323399573677e-17*sin(t1)*cos(t2) - 6.123
23399573677e-17*sin(t2)*cos(t1))*sin(t3)]
 [                                                                             ]
 [                                                                             ]
 [                    0                                                        ]
 [                                                                             ]
 [                                                                             ]
 [                    0                                                        ]
 [                                                                             ]
 [                                                                             ]
 [                    0                                                        ]
 [                                                                             ]
 [                                                                             ]
 [                  1.0                                                        ]
 [                                                                             ]

, [-1.0*l2*sin(t1)*cos(t2) - 1.0*l2*sin(t2)*cos(t1) - 1.0*l3*(-6.12323399573677e-17*
sin(t1)*sin(t2) + 6.12323399573677e-17*cos(t1)*cos(t2))*sin(t3) - 1.0*l3*(1.0*sin(t1
)*cos(t2) + 1.0*sin(t2)*cos(t1))*cos(t3)
```

```
  [

  [-1.0*l2*sin(t1)*sin(t2) + 1.0*l2*cos(t1)*cos(t2) + 1.0*l3*(-1.0*sin(t1)*sin(t2) +
 1.0*cos(t1)*cos(t2))*cos(t3) + 1.0*l3*(-6.12323399573677e-17*sin(t1)*cos(t2) - 6.12
323399573677e-17*sin(t2)*cos(t1))*sin(t3)
  [

  [
                    0

  [

  [
                    0

  [

  [
                    0

  [

  [
                  1.0

], [                                                                          -6.12323399
573677e-17*l3*(-6.12323399573677e-17*sin(t1)*sin(t2) + 6.12323399573677e-17*cos(t1)*
cos(t2))*sin(t3) + 1.0*l3*(1.0*sin(t1)*si
]  [

]  [                                                                         6.123233995
73677e-17*l3*(-1.0*sin(t1)*sin(t2) + 1.0*cos(t1)*cos(t2))*cos(t3) + 6.12323399573677
e-17*l3*(-6.12323399573677e-17*sin(t1)*co
]  [

]  [-(1.0*sin(t1)*sin(t2) - 1.0*cos(t1)*cos(t2))*(l3*(-1.0*sin(t1)*sin(t2) + 1.0*cos
(t1)*cos(t2))*cos(t3) + l3*(-6.12323399573677e-17*sin(t1)*cos(t2) - 6.12323399573677
e-17*sin(t2)*cos(t1))*sin(t3)) + (1.0*sin
]  [

]  [

          1.0*sin(t1)*cos(t2) + 1.0*sin(t
]  [

]  [

          1.0*sin(t1)*sin(t2) - 1.0*cos(t
]  [

]  [

                  6.12323399573677e-17

n(t2) - 1.0*cos(t1)*cos(t2))*sin(t3) - 6.12323399573677e-17*l3*(1.0*sin(t1)*cos(t2)
+ 1.0*sin(t2)*cos(t1))*cos(t3)
               ]]


               ]
s(t2) - 6.12323399573677e-17*sin(t2)*cos(t1))*sin(t3) - 1.0*l3*(1.0*sin(t1)*cos(t2)
+ 1.0*sin(t2)*cos(t1))*sin(t3)
```

```
                ]


                ]
(t1)*cos(t2) + 1.0*sin(t2)*cos(t1))*(l3*(-6.12323399573677e-17*sin(t1)*sin(t2) + 6.1
2323399573677e-17*cos(t1)*cos(t2))*sin(t3) + l3*(1.0*sin(t1)*cos(t2) + 1.0*sin(t2)*c
os(t1))*cos(t3))]


                ]
2)*cos(t1)

                ]


                ]
1)*cos(t2)

                ]


                ]


                ]
########## Problem 3 ##########
```