HOMEWORK - 3 Question 1 Pandas

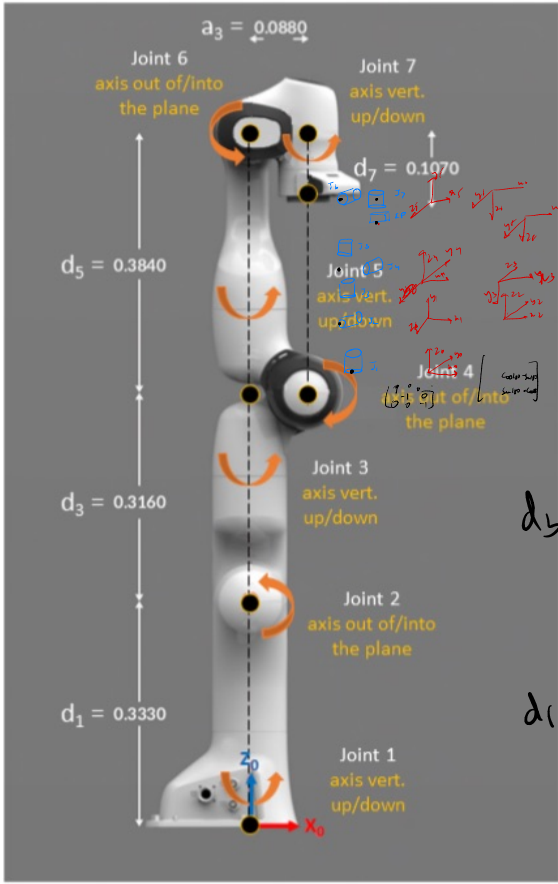
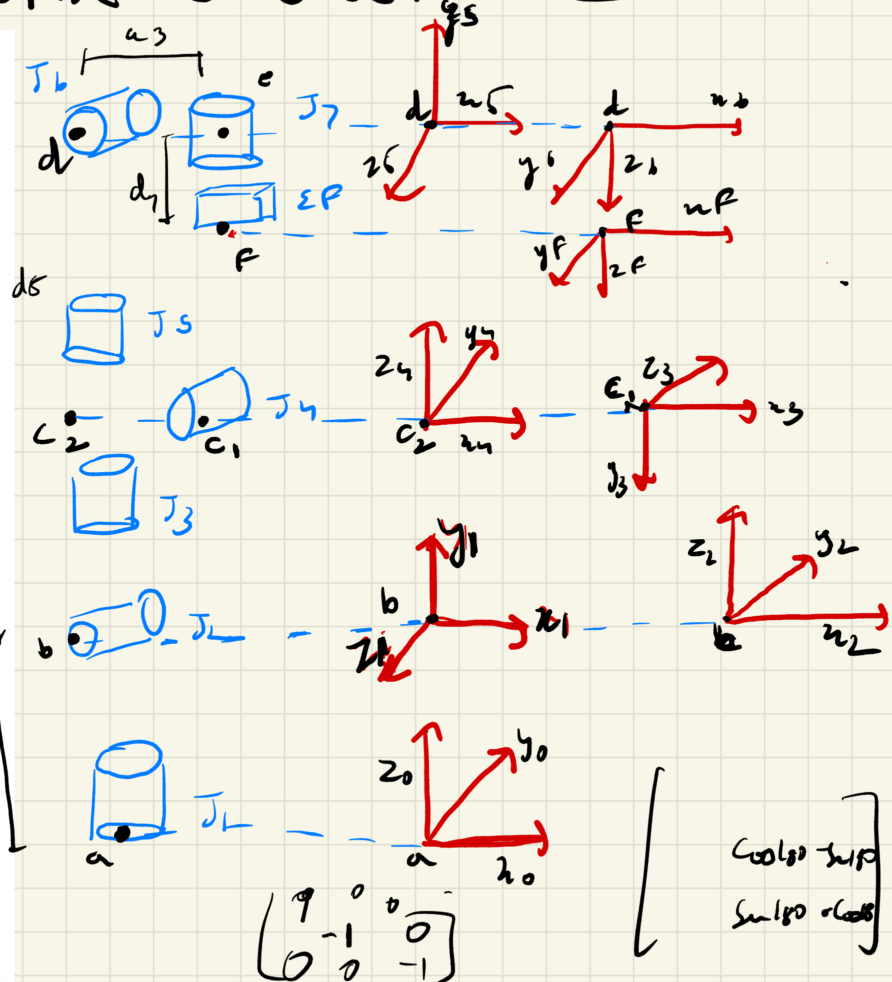


Fig. 2: Panda Robot - Home configuration

(Orange arrows indicate the positive sense of joint rotation)



DH Table from Selected frame

	θ	d	a	α
1	θ_1	d_1	0	$\pi/2$
2	θ_2	0	0	$-\pi/2$
3	θ_3	d_3	$+a_3$	$-\pi/2$
4	θ_4	0	$-a_3$	$\pi/2$
5	θ_5	d_5	0	$\pi/2$
6	θ_6	0	a_3	$\pi/2$
7	θ_7	d_7	0	0

Sprongs

$x_i \perp z_{i-1}$
n

D-H parameters

d_i : x_i distance from x_{i-1} along z_{i-1}

θ_i : x_i angle from x_{i-1} around z_{i-1}

a_i : z_i distance from z_{i-1} along x_i

α_i : z_i angle from z_{i-1} around x_i

=) This is computed in Jupyter notebook

=) The 5 geometric configurations are also made in the code

=) Ever T_i is also been printed in it.

HOMEWORK - 03

1. Position Kinematics - Panda [3.5 points]

In [1]:
```
from sympy import *
from IPython.display import Image,display,HTML
init_printing()

theta,d,a,alpha=symbols('theta,d,a,alpha')
d_1,d_3,d_5,d_7,a_3=symbols('d_1,d_3,d_5,d_7,a_3')
theta_1,theta_2,theta_3,theta_4,theta_5,theta_6,theta_7=symbols('theta_1,theta_2,theta_3
Rot_z_theta=Matrix([[cos(theta),-sin(theta),0,0],
                    [sin(theta),cos(theta),0,0],
                    [0,0,1,0],
                    [0,0,0,1]])
Trans_z_d=Matrix([[1,0,0,0],
                  [0,1,0,0],
                  [0,0,1,d],
                  [0,0,0,1]])
Trans_x_a=Matrix([[1,0,0,a],
                  [0,1,0,0],
                  [0,0,1,0],
                  [0,0,0,1]])
Rot_x_alpha=Matrix([[1,0,0,0],
                   [0,cos(alpha),-sin(alpha),0],
                   [0,sin(alpha),cos(alpha),0],
                   [0,0,0,1]])
```

ROTATION MATRIX COMPUTATION

In [2]:
```
A=Rot_z_theta*Trans_z_d*Trans_x_a*Rot_x_alpha
```

ROTATION MATRIX COMPUTATION FOR EACH JOINT

In [3]:
```
A_1=A.subs({theta:theta_1,d:d_1,a:0,alpha:pi/2})
A_2=A.subs({theta:theta_2,d:0,a:0,alpha:-pi/2})
A_3=A.subs({theta:theta_3,d:d_3,a:a_3,alpha:-pi/2})
A_4=A.subs({theta:theta_4,d:0,a:-a_3,alpha:pi/2})
A_5=A.subs({theta:theta_5,d:d_5,a:0,alpha:pi/2})
A_6=A.subs({theta:theta_6,d:0,a:a_3,alpha:pi/2})
A_7=A.subs({theta:theta_7,d:d_7,a:0,alpha:0})
```

In [4]:
```
A_1
```

Out[4]:

$$\begin{bmatrix} \cos(\theta_1) & 0 & \sin(\theta_1) & 0 \\ \sin(\theta_1) & 0 & -\cos(\theta_1) & 0 \\ 0 & 1 & 0 & d_1 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

In [5]:
```
A_2
```

Out[5]:
$$\left[\begin{matrix}\cos{\left(\theta_{2} \right)} & 0 & - \sin{\left(\theta_{2} \right)} & 0\\\sin{\left(\theta_{2} \right)} & 0 & \cos{\left(\theta_{2} \right)} & 0\\0 & -1 & 0 & 0\\0 & 0 & 0 & 1\end{matrix}\right]$$

In [6]:
```
A_3
```

Out[6]:
$$\left[\begin{matrix}\cos{\left(\theta_{3} \right)} & 0 & - \sin{\left(\theta_{3} \right)} & a_{3} \cos{\left(\theta_{3} \right)}\\\sin{\left(\theta_{3} \right)} & 0 & \cos{\left(\theta_{3} \right)} & a_{3} \sin{\left(\theta_{3} \right)}\\0 & -1 & 0 & d_{3}\\0 & 0 & 0 & 1\end{matrix}\right]$$

In [7]:
```
A_4
```

Out[7]:
$$\left[\begin{matrix}\cos{\left(\theta_{4} \right)} & 0 & \sin{\left(\theta_{4} \right)} & - a_{3} \cos{\left(\theta_{4} \right)}\\\sin{\left(\theta_{4} \right)} & 0 & - \cos{\left(\theta_{4} \right)} & - a_{3} \sin{\left(\theta_{4} \right)}\\0 & 1 & 0 & 0\\0 & 0 & 0 & 1\end{matrix}\right]$$

In [8]:
```
A_5
```

Out[8]:
$$\left[\begin{matrix}\cos{\left(\theta_{5} \right)} & 0 & \sin{\left(\theta_{5} \right)} & 0\\\sin{\left(\theta_{5} \right)} & 0 & - \cos{\left(\theta_{5} \right)} & 0\\0 & 1 & 0 & d_{5}\\0 & 0 & 0 & 1\end{matrix}\right]$$

In [9]:
```
A_6
```

Out[9]:
$$\left[\begin{matrix}\cos{\left(\theta_{6} \right)} & 0 & \sin{\left(\theta_{6} \right)} & a_{3} \cos{\left(\theta_{6} \right)}\\\sin{\left(\theta_{6} \right)} & 0 & - \cos{\left(\theta_{6} \right)} & a_{3} \sin{\left(\theta_{6} \right)}\\0 & 1 & 0 & 0\\0 & 0 & 0 & 1\end{matrix}\right]$$

In [10]:
```
A_7
```

Out[10]:
$$\left[\begin{matrix}\cos{\left(\theta_{7} \right)} & - \sin{\left(\theta_{7} \right)} & 0 & 0\\\sin{\left(\theta_{7} \right)} & \cos{\left(\theta_{7} \right)} & 0 & 0\\0 & 0 & 1 & d_{7}\\0 & 0 & 0 & 1\end{matrix}\right]$$

THE FINAL TRANFORMATION OF EF WRT ORIGIN

In [11]:
```
Transformation=A_1*A_2*A_3*A_4*A_5*A_6*A_7
Transformation
```

Out[11]:

$$\left[\begin{matrix}\left(\left(\left(\left(- \sin{\left(\theta_{1} \right)} \sin{\left(\theta_{3} \right)} + \cos{\left(\theta_{1} \right)} \cos{\left(\theta_{2} \right)} \cos{\left(\theta_{3} \right)}\right) \cos{\left(\theta_{4} \right)} + \sin{\left(\theta_{2} \right)} \sin{\left(\theta_{4} \right)} \cos{\left(\theta_{1} \right)}\right) \cos{\left(\theta_{5} \right)} + \left(- \sin{\left(\theta_{1} \right)} \cos{\left(\theta_{3} \right)} - \sin{\left(\theta_{3} \right)} \cos{\left(\theta_{1} \right)} \cos{\left(\theta_{2} \right)}\right) \sin{\left(\theta_{5} \right)}\right) \cos{\left(\theta_{6} \right)} + \left(\left(- \sin{\left(\theta_{1} \right)} \sin{\left(\theta_{3} \right)} + \cos{\left(\theta_{1} \right)} \cos{\left(\theta_{2} \right)} \cos{\left(\theta_{3} \right)}\right) \sin{\left(\theta_{4} \right)} - \sin{\left(\theta_{2} \right)} \cos{\left(\theta_{1} \right)} \cos{\left(\theta_{4} \right)}\right) \sin{\left(\theta_{6} \right)}\right) \cos{\left(\theta_{7} \right)} + \left(\left(\left(- \sin{\left(\theta_{1} \right)} \sin{\left(\theta_{3} \right)} + \cos{\left(\theta_{1} \right)} \cos{\left(\theta_{2} \right)} \cos{\left(\theta_{3} \right)}\right) \cos{\left(\theta_{4} \right)} + \sin{\left(\theta_{2} \right)} \sin{\left(\theta_{4} \right)} \cos{\left(\theta_{1} \right)}\right) \sin{\left(\theta_{5} \right)} - \left(- \sin{\left(\theta_{1} \right)} \cos{\left(\theta_{3} \right)} - \sin{\left(\theta_{3} \right)} \cos{\left(\theta_{1} \right)} \cos{\left(\theta_{2} \right)}\right) \cos{\left(\theta_{5} \right)}\right) \sin{\left(\theta_{7} \right)}\\\left(\left(\left(\left(\sin{\left(\theta_{1} \right)} \cos{\left(\theta_{2} \right)} \cos{\left(\theta_{3} \right)} + \sin{\left(\theta_{3} \right)} \cos{\left(\theta_{1} \right)}\right) \cos{\left(\theta_{4} \right)} + \sin{\left(\theta_{1} \right)} \sin{\left(\theta_{2} \right)} \sin{\left(\theta_{4} \right)}\right) \cos{\left(\theta_{5} \right)} + \left(- \sin{\left(\theta_{1} \right)} \sin{\left(\theta_{3} \right)} \cos{\left(\theta_{2} \right)} + \cos{\left(\theta_{1} \right)} \cos{\left(\theta_{3} \right)}\right) \sin{\left(\theta_{5} \right)}\right) \cos{\left(\theta_{6} \right)} + \left(\left(\sin{\left(\theta_{1} \right)} \cos{\left(\theta_{2} \right)} \cos{\left(\theta_{3} \right)} + \sin{\left(\theta_{3} \right)} \cos{\left(\theta_{1} \right)}\right) \sin{\left(\theta_{4} \right)} - \sin{\left(\theta_{1} \right)} \sin{\left(\theta_{2} \right)} \cos{\left(\theta_{4} \right)}\right) \sin{\left(\theta_{6} \right)}\right) \cos{\left(\theta_{7} \right)} + \left(\left(\left(\sin{\left(\theta_{1} \right)} \cos{\left(\theta_{2} \right)} \cos{\left(\theta_{3} \right)} + \sin{\left(\theta_{3} \right)} \cos{\left(\theta_{1} \right)}\right) \cos{\left(\theta_{4} \right)} + \sin{\left(\theta_{1} \right)} \sin{\left(\theta_{2} \right)} \sin{\left(\theta_{4} \right)}\right) \sin{\left(\theta_{5} \right)} - \left(- \sin{\left(\theta_{1} \right)} \sin{\left(\theta_{3} \right)} \cos{\left(\theta_{2} \right)} + \cos{\left(\theta_{1} \right)} \cos{\left(\theta_{3} \right)}\right) \cos{\left(\theta_{5} \right)}\right) \sin{\left(\theta_{7} \right)}\\\left(\left(\left(\sin{\left(\theta_{2} \right)} \cos{\left(\theta_{3} \right)} \cos{\left(\theta_{4} \right)} - \sin{\left(\theta_{4} \right)} \cos{\left(\theta_{2} \right)}\right) \cos{\left(\theta_{5} \right)} - \sin{\left(\theta_{2} \right)} \sin{\left(\theta_{3} \right)} \sin{\left(\theta_{5} \right)}\right) \cos{\left(\theta_{6} \right)} + \left(\sin{\left(\theta_{2} \right)} \sin{\left(\theta_{4} \right)} \cos{\left(\theta_{3} \right)} + \cos{\left(\theta_{2} \right)} \cos{\left(\theta_{4} \right)}\right) \sin{\left(\theta_{6} \right)}\right) \cos{\left(\theta_{7} \right)} + \left(\left(\sin{\left(\theta_{2} \right)} \cos{\left(\theta_{3} \right)} \cos{\left(\theta_{4} \right)} - \sin{\left(\theta_{4} \right)} \cos{\left(\theta_{2} \right)}\right) \sin{\left(\theta_{5} \right)} + \sin{\left(\theta_{2} \right)} \sin{\left(\theta_{3} \right)} \cos{\left(\theta_{5} \right)}\right) \sin{\left(\theta_{7} \right)}\\0\end{matrix}\right]$$

TRANSFOMATION RESULTS FOR GEOMETRICALLY KNOW CONFIGRATIONS

Theta2 is rotated by pi/2

In [12]:

```
T_1=Transformation.subs({theta_1:0,
theta_2:pi/2,
theta_3:0,
theta_4:0,
theta_5:0,
theta_6:0,
theta_7:0})
T_1
```

Out[12]:

$$\left[\begin{matrix}0 & 0 & 1 & - d_{3} - d_{5} + d_{7}\\0 & -1 & 0 & 0\\1 & 0 & 0 & a_{3} + d_{1}\\0 & 0 & 0 & 1\end{matrix}\right]$$

All angles are zero home configration

In [13]:
```
T_1=Transformation.subs({theta_1:0,
theta_2:0,
theta_3:0,
theta_4:0,
theta_5:0,
theta_6:0,
theta_7:0})
T_1
```

* Home Position

Out[13]:

$$\begin{bmatrix} 1 & 0 & 0 & a_3 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & -1 & d_1 + d_3 + d_5 - d_7 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Theta3 is rotated by pi/2

In [14]:
```
T_1=Transformation.subs({theta_1:0,
theta_2:0,
theta_3:pi/2,
theta_4:0,
theta_5:0,
theta_6:0,
theta_7:0})
T_1
```

Out[14]:

$$\begin{bmatrix} 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & a_3 \\ 0 & 0 & -1 & d_1 + d_3 + d_5 - d_7 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Theta4 is rotated by pi/2

In [15]:
```
T_1=Transformation.subs({theta_1:0,
theta_2:0,
theta_3:0,
theta_4:pi/2,
theta_5:0,
theta_6:0,
theta_7:0})
T_1
```

Out[15]:

$$\begin{bmatrix} 0 & 0 & -1 & a_3 + d_5 - d_7 \\ 0 & -1 & 0 & 0 \\ -1 & 0 & 0 & d_1 + d_3 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Theta5 is rotated by pi/2

In [16]:
```
T_1=Transformation.subs({theta_1:0,
theta_2:0,
theta_3:0,
theta_4:0,
```

```
theta_5:pi/2,
theta_6:0,
theta_7:0})
T_1
```

Out[16]:

$$\begin{bmatrix} 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & a_3 \\ 0 & 0 & -1 & d_1 + d_3 + d_5 - d_7 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Theta6 is rotated by pi/2

In [17]:

```
T_1=Transformation.subs({theta_1:0,
theta_2:0,
theta_3:0,
theta_4:0,
theta_5:0,
theta_6:pi/2,
theta_7:0})
T_1
```

Out[17]:

$$\begin{bmatrix} 0 & 0 & 1 & d_7 \\ 0 & -1 & 0 & 0 \\ 1 & 0 & 0 & a_3 + d_1 + d_3 + d_5 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Theta7 is rotated by pi/2

In [18]:

```
T_1=Transformation.subs({theta_1:0,
theta_2:0,
theta_3:0,
theta_4:0,
theta_5:0,
theta_6:0,
theta_7:pi/2})
T_1
```

Out[18]:

$$\begin{bmatrix} 0 & -1 & 0 & a_3 \\ -1 & 0 & 0 & 0 \\ 0 & 0 & -1 & d_1 + d_3 + d_5 - d_7 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Theta 7 is roated by pi/2

In [19]:

```
T_1=Transformation.subs({theta_1:0,
theta_2:0,
theta_3:0,
theta_4:0,
theta_5:0,
theta_6:0,
theta_7:pi/2})
T_1
```

Out[19]:
$$\left[\begin{matrix}0 & -1 & 0 & a_{3}\\-1 & 0 & 0 & 0\\0 & 0 & -1 & d_{1} + d_{3} + d_{5} - d_{7}\\0 & 0 & 0 & 1\end{matrix}\right]$$

In [20]:
```
pip install nbconvert
```

Question-2 Kuka Robot

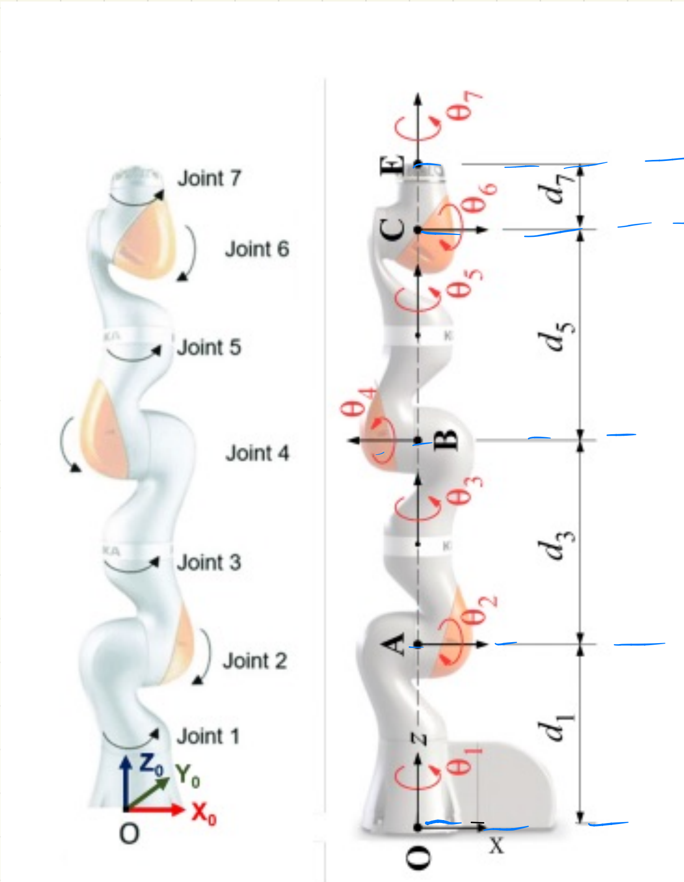
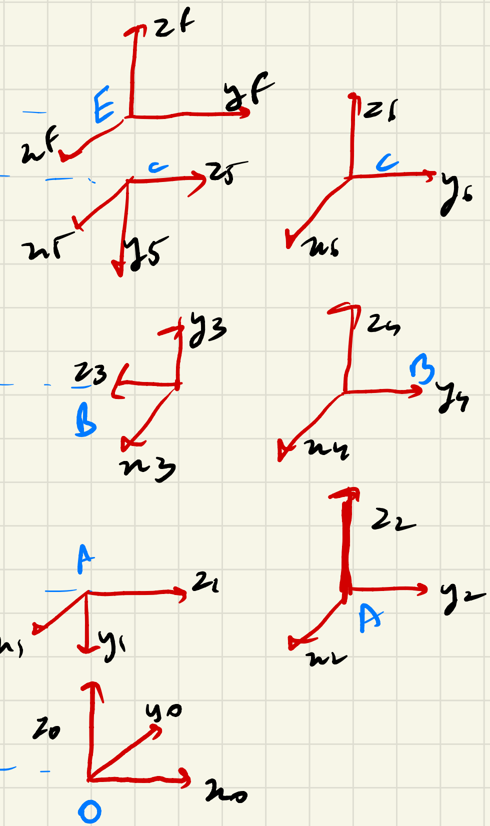


Fig.3: Kuka Robot - Home configuration



$x_i \perp z_{i-1}$
$\cap$

D-H parameters

d_i : x_i distance from x_{i-1} along z_{i-1}

θ_i : x_i angle from x_{i-1} around z_{i-1}

a_i : z_i distance from z_{i-1} along x_i

α_i : z_i angle from z_{i-1} around x_i

DH Table Spong

		θ	d	a	α
1	1	$270+\theta_1$	d_1	0	$-\pi/2$
2	2	θ_2	0	0	$\pi/2$
3	3	θ_3	d_3	0	$\pi/2$
4, 5	4	θ_4	0	0	$-\pi/2$
6	5	θ_5	d_3	0	$-\pi/2$
7	6	θ_6	0	0	$\pi/2$
	7	θ_7	d_7	0	0