```
syms theta1 theta2 theta3 real
syms l1 l2 l3 real
dh = [theta1, l1, -pi/2, 0;
      theta2,  0,     0, l2;
      theta3,  0,     0, l3];

n_dof = size(dh,1);
As=cell(1,n_dof);
Ts=cell(1,n_dof+1); % T00 T01 T02 T03
T = eye(4);
Ts{1} = T;
for i=1:n_dof
    A = dh_matrix(dh(i,:));
    T = T*A;
    As{i} = A; A
    Ts{i+1} = T;T
end
```

A =

$$\begin{pmatrix} \cos(\theta_1) & 0 & -\sin(\theta_1) & 0 \\ \sin(\theta_1) & 0 & \cos(\theta_1) & 0 \\ 0 & -1 & 0 & l_1 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

T =

$$\begin{pmatrix} \cos(\theta_1) & 0 & -\sin(\theta_1) & 0 \\ \sin(\theta_1) & 0 & \cos(\theta_1) & 0 \\ 0 & -1 & 0 & l_1 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

A =

$$\begin{pmatrix} \cos(\theta_2) & -\sin(\theta_2) & 0 & l_2\cos(\theta_2) \\ \sin(\theta_2) & \cos(\theta_2) & 0 & l_2\sin(\theta_2) \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

T =

$$\begin{pmatrix} \cos(\theta_1)\cos(\theta_2) & -\cos(\theta_1)\sin(\theta_2) & -\sin(\theta_1) & l_2\cos(\theta_1)\cos(\theta_2) \\ \cos(\theta_2)\sin(\theta_1) & -\sin(\theta_1)\sin(\theta_2) & \cos(\theta_1) & l_2\cos(\theta_2)\sin(\theta_1) \\ -\sin(\theta_2) & -\cos(\theta_2) & 0 & l_1 - l_2\sin(\theta_2) \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

A =

$$\begin{pmatrix} \cos(\theta_3) & -\sin(\theta_3) & 0 & l_3\cos(\theta_3) \\ \sin(\theta_3) & \cos(\theta_3) & 0 & l_3\sin(\theta_3) \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

T =

$$\begin{pmatrix} \cos(\theta_1)\cos(\theta_2)\cos(\theta_3) - \cos(\theta_1)\sin(\theta_2)\sin(\theta_3) & -\cos(\theta_1)\cos(\theta_2)\sin(\theta_3) - \cos(\theta_1)\cos(\theta_3)\sin(\theta_2) & -\sin(\theta \\ \cos(\theta_2)\cos(\theta_3)\sin(\theta_1) - \sin(\theta_1)\sin(\theta_2)\sin(\theta_3) & -\cos(\theta_2)\sin(\theta_1)\sin(\theta_3) - \cos(\theta_3)\sin(\theta_1)\sin(\theta_2) & \cos(\theta_1 \\ -\cos(\theta_2)\sin(\theta_3) - \cos(\theta_3)\sin(\theta_2) & \sin(\theta_2)\sin(\theta_3) - \cos(\theta_2)\cos(\theta_3) & 0 \\ 0 & 0 & 0 \end{pmatrix}$$

```
simplify(T)
```

ans =

$$\begin{pmatrix} \cos(\theta_2+\theta_3)\cos(\theta_1) & -\sin(\theta_2+\theta_3)\cos(\theta_1) & -\sin(\theta_1) & \cos(\theta_1)\,\sigma_1 \\ \cos(\theta_2+\theta_3)\sin(\theta_1) & -\sin(\theta_2+\theta_3)\sin(\theta_1) & \cos(\theta_1) & \sin(\theta_1)\,\sigma_1 \\ -\sin(\theta_2+\theta_3) & -\cos(\theta_2+\theta_3) & 0 & l_1 - l_3\sin(\theta_2+\theta_3) - l_2\sin(\theta_2) \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

where

$$\sigma_1 = l_3\cos(\theta_2+\theta_3) + l_2\cos(\theta_2)$$

```
syms nx ny nz ox oy oz ax ay az px py pz real
T03 = [nx, ox, ax, px;
       ny, oy, ay, py;
       nz, oz, az, pz;
        0,  0,  0,  1];
T03
```

T03 =

$$\begin{pmatrix} \mathrm{nx} & \mathrm{ox} & \mathrm{ax} & \mathrm{px} \\ \mathrm{ny} & \mathrm{oy} & \mathrm{ay} & \mathrm{py} \\ \mathrm{nz} & \mathrm{oz} & \mathrm{az} & \mathrm{pz} \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

```
simplify(inv(As{1})*T03)
```

ans =

$$\begin{pmatrix} \mathrm{nx}\cos(\theta_1) + \mathrm{ny}\sin(\theta_1) & \mathrm{ox}\cos(\theta_1) + \mathrm{oy}\sin(\theta_1) & \mathrm{ax}\cos(\theta_1) + \mathrm{ay}\sin(\theta_1) & \mathrm{px}\cos(\theta_1) + \mathrm{py}\sin(\theta_1) \\ -\mathrm{nz} & -\mathrm{oz} & -\mathrm{az} & l_1 - \mathrm{pz} \\ \mathrm{ny}\cos(\theta_1) - \mathrm{nx}\sin(\theta_1) & \mathrm{oy}\cos(\theta_1) - \mathrm{ox}\sin(\theta_1) & \mathrm{ay}\cos(\theta_1) - \mathrm{ax}\sin(\theta_1) & \mathrm{py}\cos(\theta_1) - \mathrm{px}\sin(\theta_1) \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

```
simplify(As{2}*As{3})
```

ans =

$$\begin{pmatrix} \cos(\theta_2+\theta_3) & -\sin(\theta_2+\theta_3) & 0 & l_3\cos(\theta_2+\theta_3)+l_2\cos(\theta_2) \\ \sin(\theta_2+\theta_3) & \cos(\theta_2+\theta_3) & 0 & l_3\sin(\theta_2+\theta_3)+l_2\sin(\theta_2) \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

```
simplify(inv(As{2})*inv(As{1})*T03)
```

ans =

$$\begin{pmatrix} \mathrm{nx}\cos(\theta_1)\cos(\theta_2)-\mathrm{nz}\sin(\theta_2)+\mathrm{ny}\cos(\theta_2)\sin(\theta_1) & \mathrm{ox}\cos(\theta_1)\cos(\theta_2)-\mathrm{oz}\sin(\theta_2)+\mathrm{oy}\cos(\theta_2)\sin(\theta_1) \\ -\mathrm{nz}\cos(\theta_2)-\mathrm{nx}\cos(\theta_1)\sin(\theta_2)-\mathrm{ny}\sin(\theta_1)\sin(\theta_2) & -\mathrm{oz}\cos(\theta_2)-\mathrm{ox}\cos(\theta_1)\sin(\theta_2)-\mathrm{oy}\sin(\theta_1)\sin(\theta_2) \\ \mathrm{ny}\cos(\theta_1)-\mathrm{nx}\sin(\theta_1) & \mathrm{oy}\cos(\theta_1)-\mathrm{ox}\sin(\theta_1) \\ 0 & 0 \end{matrix}$$

```
As{3}
```

ans =

$$\begin{pmatrix} \cos(\theta_3) & -\sin(\theta_3) & 0 & l_3\cos(\theta_3) \\ \sin(\theta_3) & \cos(\theta_3) & 0 & l_3\sin(\theta_3) \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

```
simplify(inv(As{1})*T03*inv(As{3}))
```

ans =

$$\begin{pmatrix} \mathrm{nx}\cos(\theta_1)\cos(\theta_3)+\mathrm{ny}\cos(\theta_3)\sin(\theta_1)-\mathrm{ox}\cos(\theta_1)\sin(\theta_3)-\mathrm{oy}\sin(\theta_1)\sin(\theta_3) & \mathrm{ox}\cos(\theta_1)\cos(\theta_3)+\mathrm{nx}\,\mathrm{co} \\ \mathrm{oz}\sin(\theta_3)-\mathrm{nz}\cos(\theta_3) & \\ \mathrm{ny}\cos(\theta_1)\cos(\theta_3)-\mathrm{nx}\cos(\theta_3)\sin(\theta_1)-\mathrm{oy}\cos(\theta_1)\sin(\theta_3)+\mathrm{ox}\sin(\theta_1)\sin(\theta_3) & \mathrm{oy}\cos(\theta_1)\cos(\theta_3)+\mathrm{ny}\,\mathrm{co} \\ 0 & \end{matrix}$$

```
As{2}
```

ans =

$$\begin{pmatrix} \cos(\theta_2) & -\sin(\theta_2) & 0 & l_2\cos(\theta_2) \\ \sin(\theta_2) & \cos(\theta_2) & 0 & l_2\sin(\theta_2) \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$