$$\begin{pmatrix} u \\ v \\ w \end{pmatrix} = \overbrace{\underbrace{K}_{M_{int}}\underbrace{[R \mid T]}_{M_{ext}}}^{M} \begin{pmatrix} X_w \\ Y_w \\ Z_w \\ 1 \end{pmatrix}$$

$$M_{int} = K = \begin{bmatrix} -f/s_x & 0 & O_x \\ 0 & -f/s_y & O_y \\ 0 & 0 & 1 \end{bmatrix} \qquad M_{ext} = \begin{bmatrix} r_{11} & r_{12} & r_{13} & T_x \\ r_{21} & r_{22} & r_{23} & T_y \\ r_{31} & r_{32} & r_{33} & T_z \end{bmatrix}$$

Think of $M = M_{int} M_{ext}$ as a $3 \times 4$ matrix (12 numbers)

$$M = \begin{bmatrix} m_{11} & m_{12} & m_{13} & m_{14} \\ m_{21} & m_{22} & m_{23} & m_{24} \\ m_{31} & m_{32} & m_{33} & m_{34} \end{bmatrix}$$

$$x = u/w = \frac{m_{11} X_w + m_{12} Y_w + m_{13} Z_w + m_{14}}{m_{31} X_w + m_{32} Y_w + m_{33} Z_w + m_{34}}$$

$$y = v/w = \frac{m_{21} X_w + m_{22} Y_w + m_{23} Z_w + m_{24}}{m_{31} X_w + m_{32} Y_w + m_{33} Z_w + m_{34}}$$

Move all terms to one side

$$m_{11} X + m_{12} Y + m_{13} Z + m_{14} - m_{31} xX - m_{32} xY - m_{33} xZ - m_{34} x = 0$$

$$m_{21} X + m_{22} Y + m_{23} Z + m_{24} - m_{31} yX - m_{32} yY - m_{33} yZ - m_{34} y = 0$$

This true for any 3D point that projects to a 2D pixel using this projection matrix.

Assume there are $n$ such 3D → 2D projections.

$m$ is dimension 12 by 1

Then let $\bar{m} = [m_{11}\ m_{12}\ m_{13}\ m_{14}\ m_{21}\ m_{22}\ m_{23}\ m_{24}\ m_{31}\ m_{32}\ m_{33}\ m_{34}]^T$

And

$$A = \begin{bmatrix} X_1 & Y_1 & Z_1 & 1 & 0 & 0 & 0 & 0 & -x_1X_1 & -x_1Y_1 & -x_1Z_1 & -x_1 \\ 0 & 0 & 0 & 0 & X_1 & Y_1 & Z_1 & 1 & -y_1X_1 & -y_1Y_1 & -y_1Z_1 & -y_1 \\ & " & & & " & & & & " & " & & \\ & " & & & " & & & & " & & & \\ X_n & Y_n & Z_n & 1 & 0 & 0 & 0 & 0 & -x_nX_n & -x_nY_n & -x_nZ_n & -x_n \\ 0 & 0 & 0 & 0 & X_n & Y_n & Z_n & 1 & -y_nX_n & -y_nY_n & -y_nZ_n & -y_n \end{bmatrix}$$

so

$$A\bar{m} = \bar{0}$$

A is of dimension $2n \times 12$