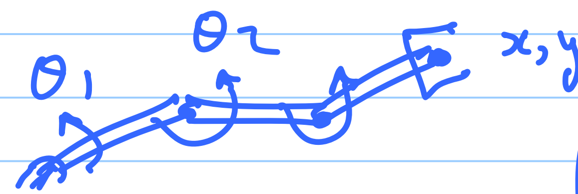
Note Title 9/20/2007

Lecture - 8+9

* Manipulator arms

"KINEMATICS":



$$\begin{pmatrix} f_1(\theta_1, \theta_2, \theta_3) \\ f_2(\theta_1, \theta_2, \theta_3) \end{pmatrix} = \begin{pmatrix} x \\ y \end{pmatrix}$$

Class of robots: open serial kinematic chains.

one end is free to move.

sequence of rigid bodies ("links")

connected via "joints". Link $i-1$ & Link i are connected by joint i. joint i moves link i.

<u>Example:</u>

ROBOTICS: CONTROL, SENSING, VISION, AND INTELLIGENCE

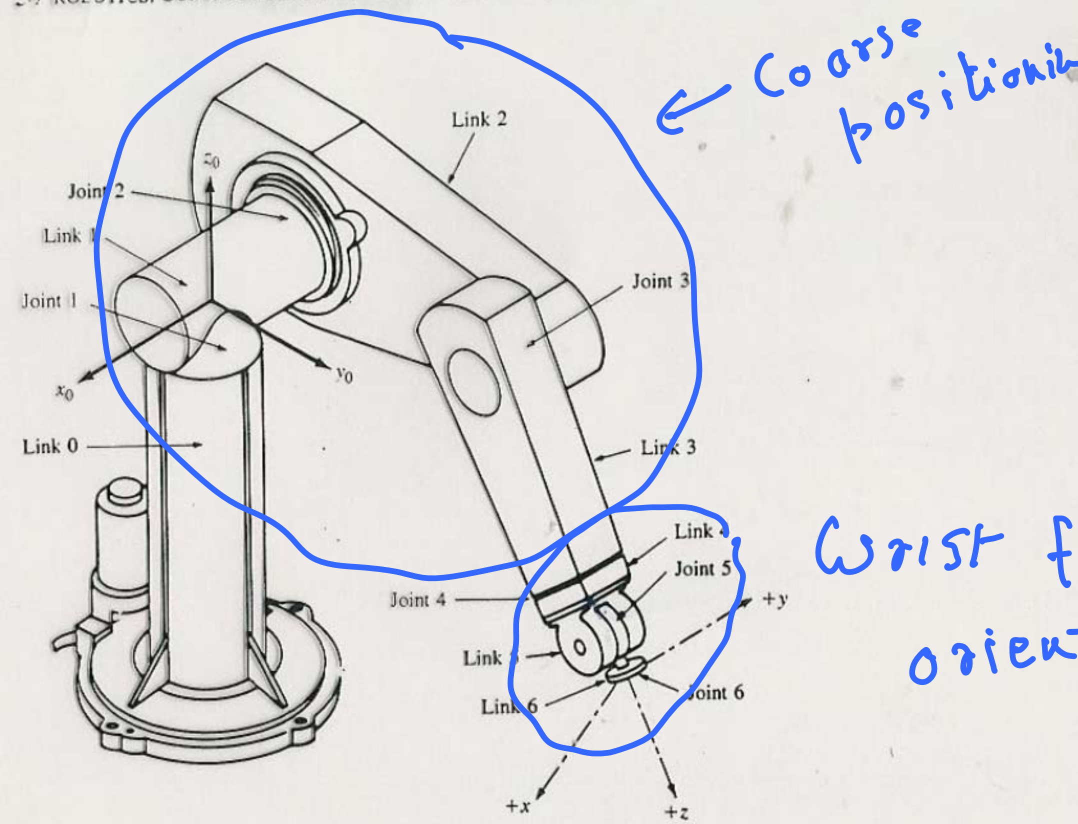


Figure 2.8 A PUMA robot arm illustrating joints and links.

dof "degrees of freedom" of a robot:

minimum # of <u>independent</u> parameters needed to specify the pos. + orient. of all components (links) of the robot.

A rigid body : $\underset{\text{pos}}{3} + \underset{\text{ori.}}{3} = 6$ parameters

hence 6-dofs

therefore, most robots for gen. pos.

tasks need at least 6-dofs.

<u>what are diff. types of joints:</u>

"Lower pair" joints: two surfaces are fully in contact.

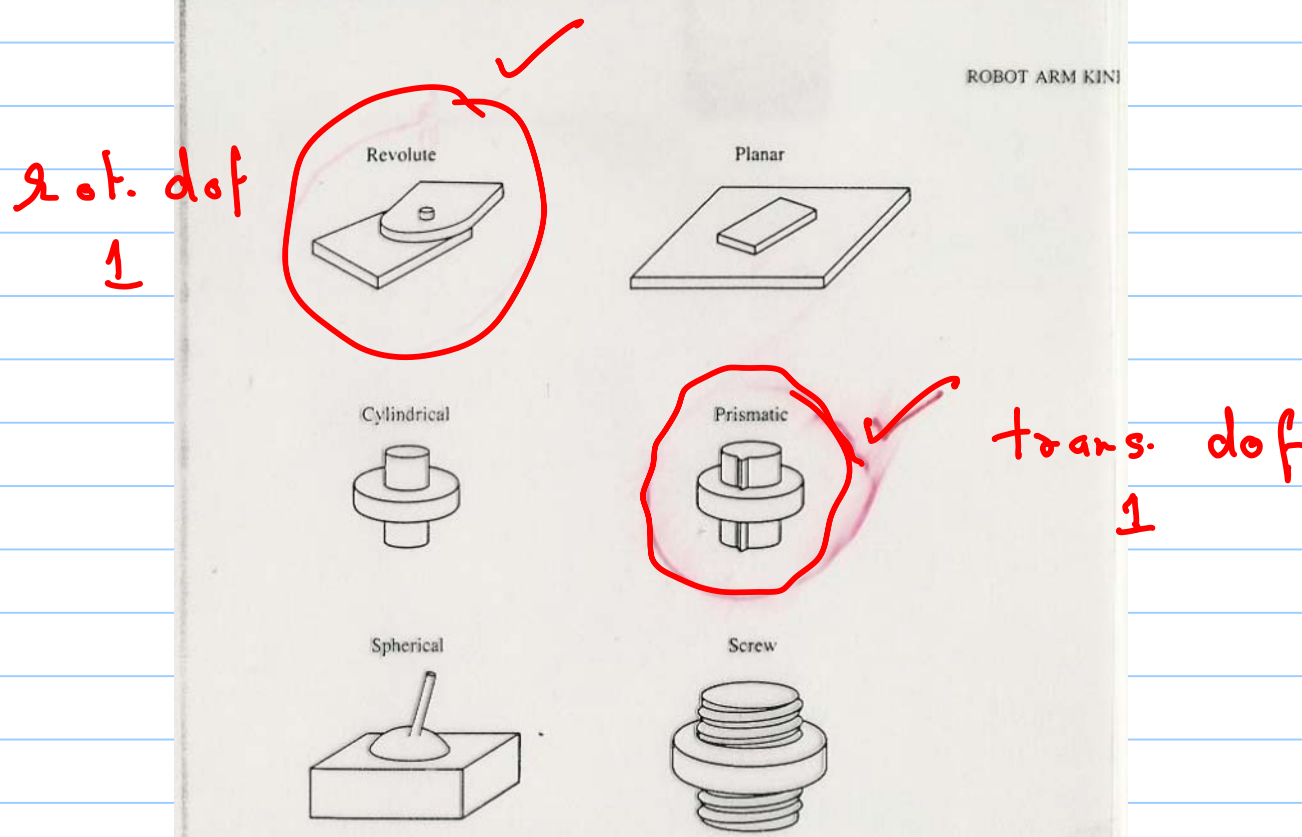


Figure 2.9 The lower pair.

Joint $i + 1$

Label / classify robots based on types of joints: R : revolute

P : prismatic

KINEMATIC CONFIG:

RRP, PPP, RRR (3R)

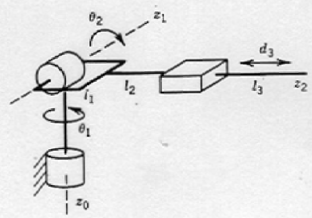


FIGURE 1-9
The spherical manipulator configuration

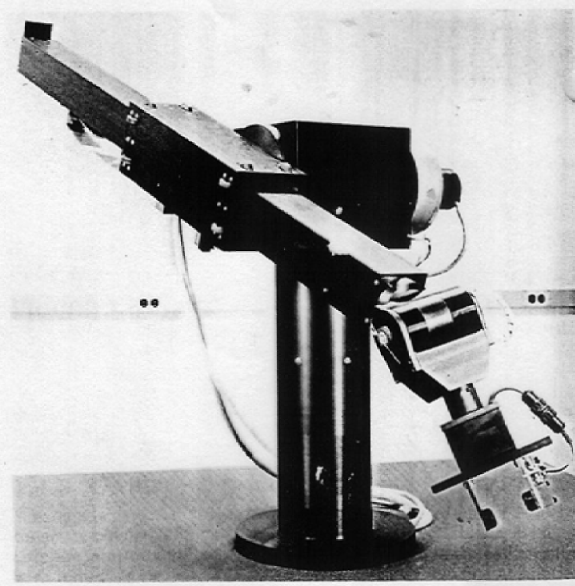


FIGURE 1-10
The Stanford manipulator

RRP

FIGURE 1-13
The AdeptOne robot. Photo courtesy of Adept Technologies.

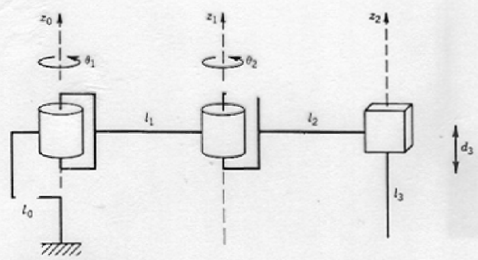


FIGURE 1-12
The SCARA (Selective Compliant Articulated Robot for Assembly)

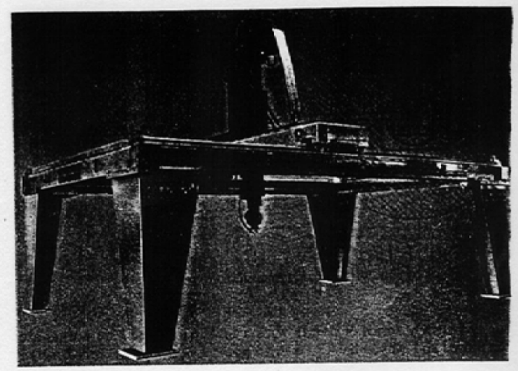


FIGURE 1-19
A Gantry robot, the Cincinnati Milacron T^3 886. Photo courtesy Cincinnati Milacron.

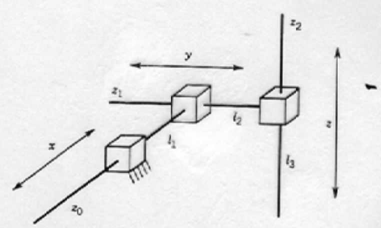


FIGURE 1-18
The cartesian manipulator configuration.

PPP

Gantry Robots

generally speaking: $\begin{cases} \text{P : more precise positioning} \\ \text{R : less precise} \end{cases}$

<u>Alternative classification</u> DRIVE Technology

→ electric

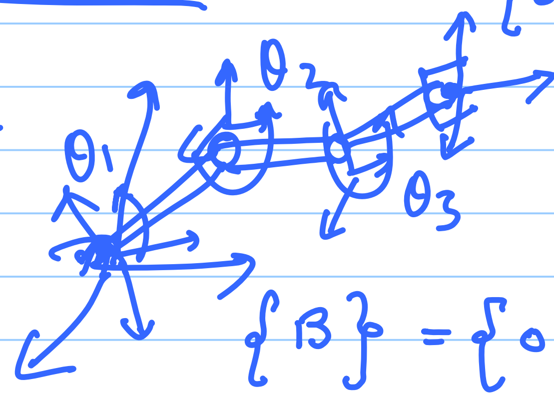
speed / precision / power → pneumatic

→ hydraulic

# of dofs

Strategy:

$${}^{0}_{N}T = {}^{0}_{1}T \, {}^{1}_{2}T \cdots {}^{N-1}_{N}T$$



$${}^{W}_{B}T = ? \quad \theta_1, \theta_2, \theta_3$$

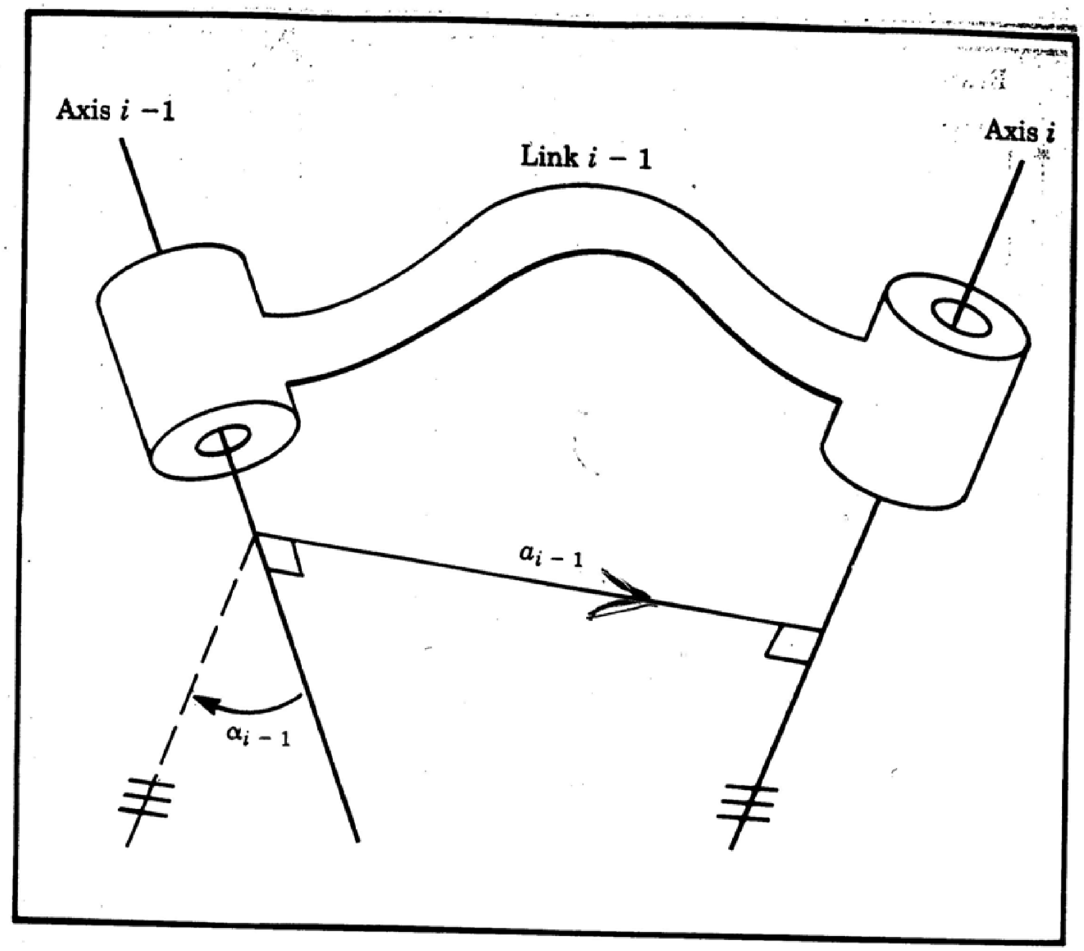
1) assign frames to each link

2) D-H Denavit & Hartenberg (1955)
Notation
for assigning frames to various links.

Consider joint axes $i-1$ & i. Common $\perp$ bet. them is denoted by a_{i-1}. α_{i-1} = angle bet. $(i-1)$ axis & i axis around common $\perp$ pointing from

a_{i-1} : link length

α_{i-1} = twist angle



$i-1$ to i

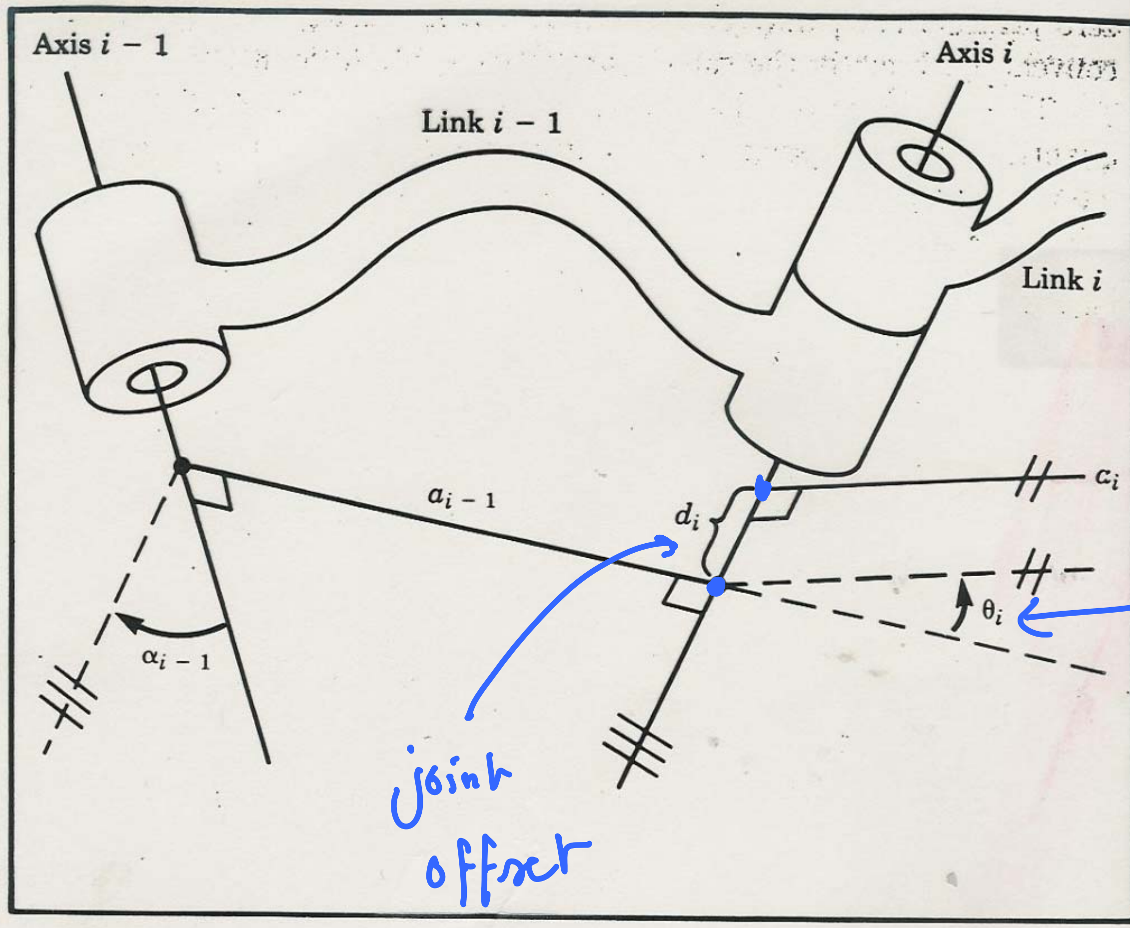
$a_{i-1}, \alpha_{i-1} \longrightarrow$ link parameters

$d_i, \theta_i \longrightarrow$ joint parameters

Var. for P

var. for R

joint variable



joint angle around axis i

D-H Notation for frame assignment:

assign $\{i\}$ to joint axis i.

Recall joint i moves link i.

1) assign $\hat{Z}_{i-1}$ to axis $i-1$.

2) assign $\hat{X}_{i-1}$ to common $\perp$ bet. axis $i-1$ & i. (along a_{i-1}) pointing from $i-1$ to i.

3) Origin of $\{i-1\}$ where the common $\perp$. bet. $(i-1)$ & i intersects $(i-1)$ axis

Relationship bet. these two $\{i-1\}$ & $\{i\}$ frames is given by: $\alpha_{i-1}, a_{i-1}, \theta_i, d_i$

$$ {}^{i-1}_{\ \ i}T = (\alpha_{i-1}, a_{i-1}, \theta_i, d_i) $$

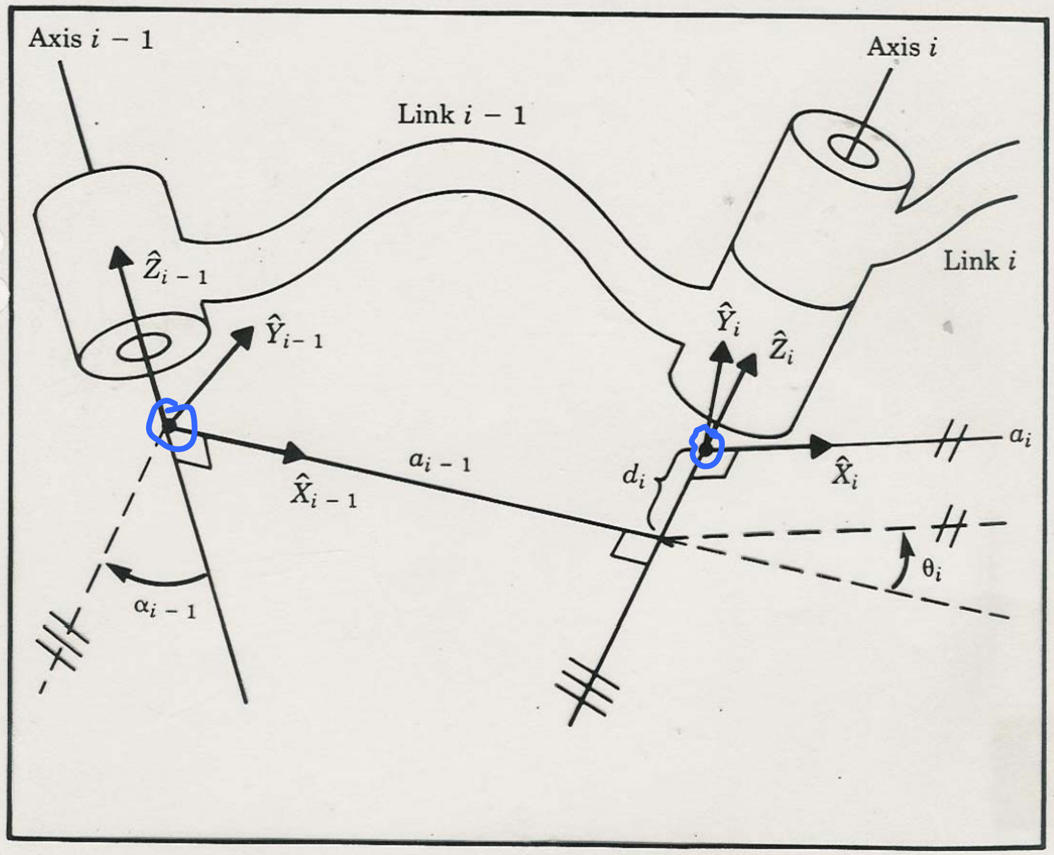


FIGURE 3.5 Link frames are attached so that frame $\{i\}$ is attached rigidly to link i.

We assign intermediate frames $\{P\}$, $\{Q\}$, $\{R\}$ (see figure 3.15 below)

$$ {}^{i-1}_{i}T = {}^{i-1}_{R}T \; {}^{R}_{Q}T \; {}^{Q}_{P}T \; {}^{P}_{i}T $$

$$ = R_X(\alpha_{i-1})\, Trans_X(a_{i-1})\, R_Z(\theta_i)\, Trans_Z(d_i) $$

We know the form of each of these matrices, combining, we get :

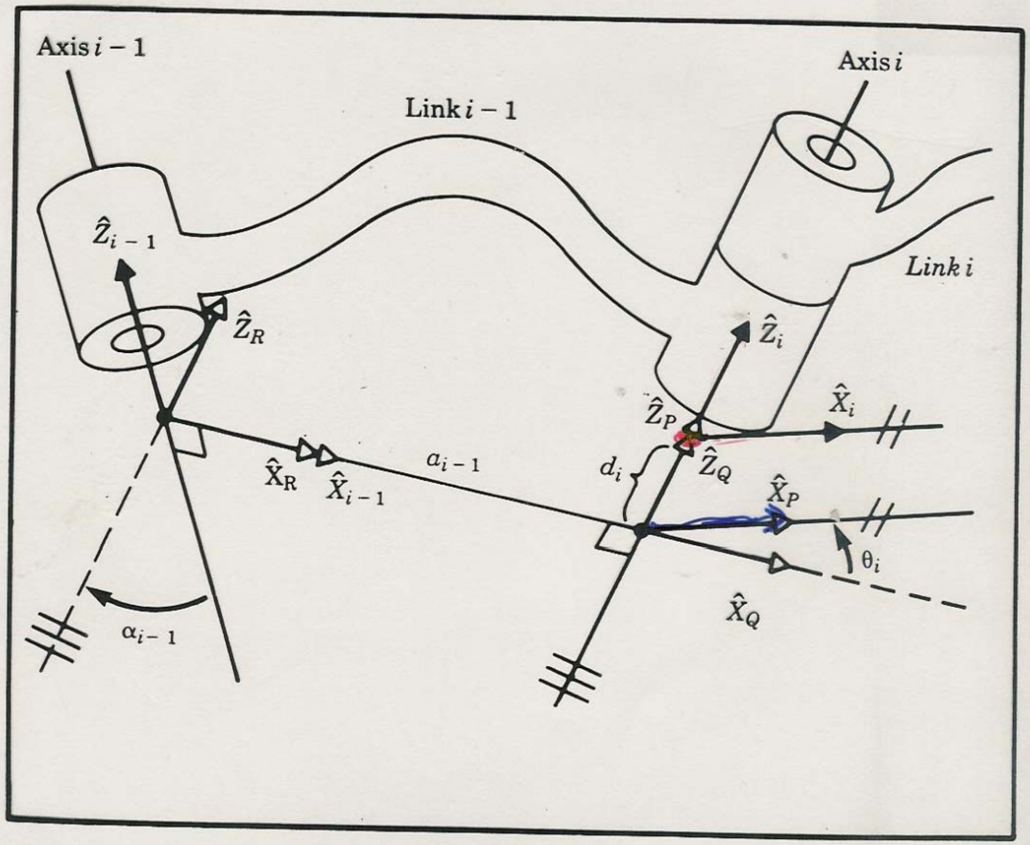


FIGURE 3.15 Location of intermediate frames $\{P\}$, $\{Q\}$, and $\{R\}$.

... vectors defined in $\{i\}$ to their description in $\{i-1\}$, we may write

$$ {}^{i-1}P = {}^{i-1}_{R}T \; {}^{R}_{Q}T \; {}^{Q}_{P}T \; {}^{P}_{i}T \; {}^{i}P, \tag{3.1} $$

or

$$ {}^{i-1}P = {}^{i-1}_{i}T \; {}^{i}P, \tag{3.2} $$

where

$$ {}^{i-1}_{i}T = {}^{i-1}_{R}T \; {}^{R}_{Q}T \; {}^{Q}_{P}T \; {}^{P}_{i}T. \tag{3.3} $$

Considering each of these transformations, we see that (3.3) may be written

$$ {}^{i-1}_{i}T = R_X(\alpha_{i-1}) D_X(a_{i-1}) R_Z(\theta_i) D_Z(d_i), \tag{3.4} $$

or

$$ {}^{i-1}_{i}T = \mathrm{Screw}_X(a_{i-1}, \alpha_{i-1}) \; \mathrm{Screw}_Z(d_i, \theta_i), \tag{3.5} $$

where the notation $\mathrm{Screw}_Q(r, \phi)$ stands for the combination of a translation along an axis $\hat{Q}$ by a distance r and a rotation about the same axis by an angle ϕ. Multiplying out (3.4), we obtain the general form of ${}^{i-1}_{i}T$:

$$ {}^{i-1}_{i}T = \begin{bmatrix} c\theta_i & -s\theta_i & 0 & a_{i-1} \\ s\theta_i c\alpha_{i-1} & c\theta_i c\alpha_{i-1} & -s\alpha_{i-1} & -s\alpha_{i-1} d_i \\ s\theta_i s\alpha_{i-1} & c\theta_i s\alpha_{i-1} & c\alpha_{i-1} & c\alpha_{i-1} d_i \\ 0 & 0 & 0 & 1 \end{bmatrix}. \tag{3.6} $$