ASSEMBLY MODELING

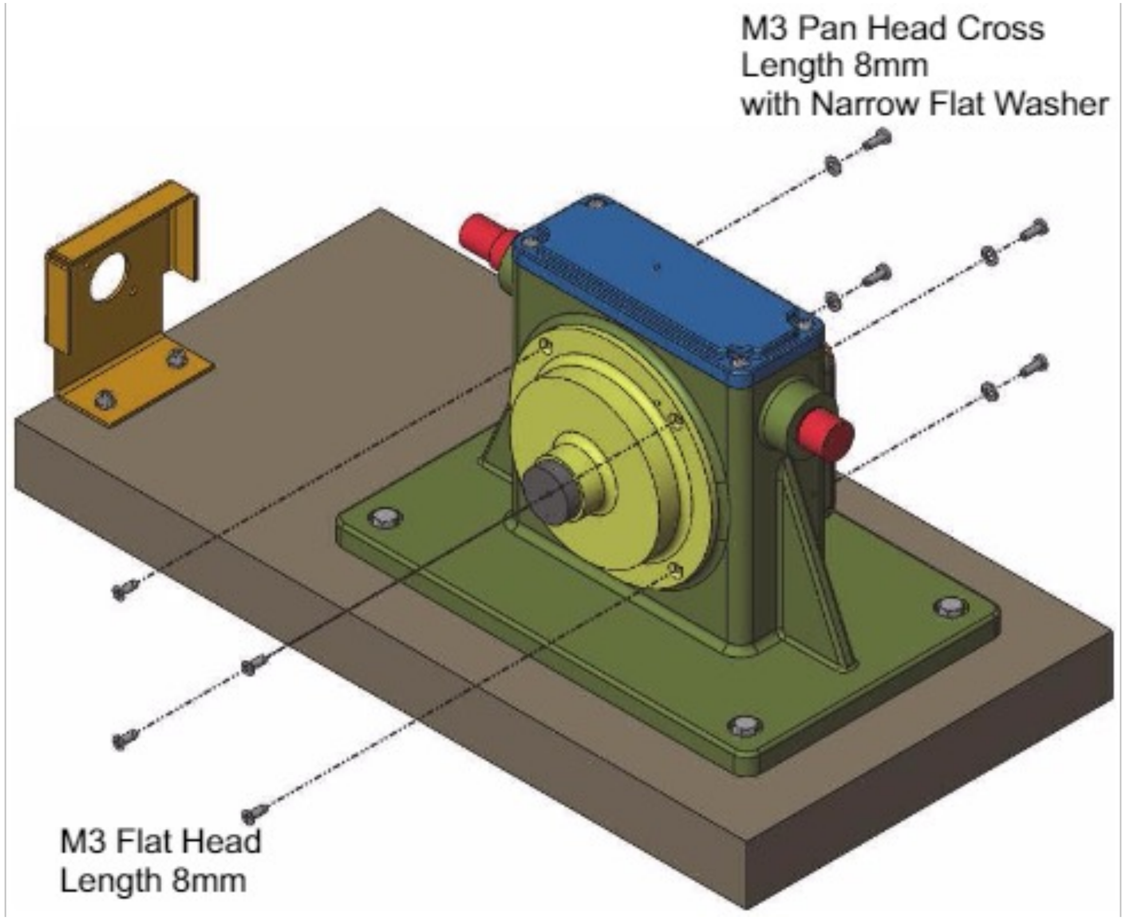
LECTURE #8

MKS 537E – Intro to CAE

Definition

Assembly modeling is a technology and method used by computer-aided design and product visualization computer software systems to handle multiple files that represent components within a product.

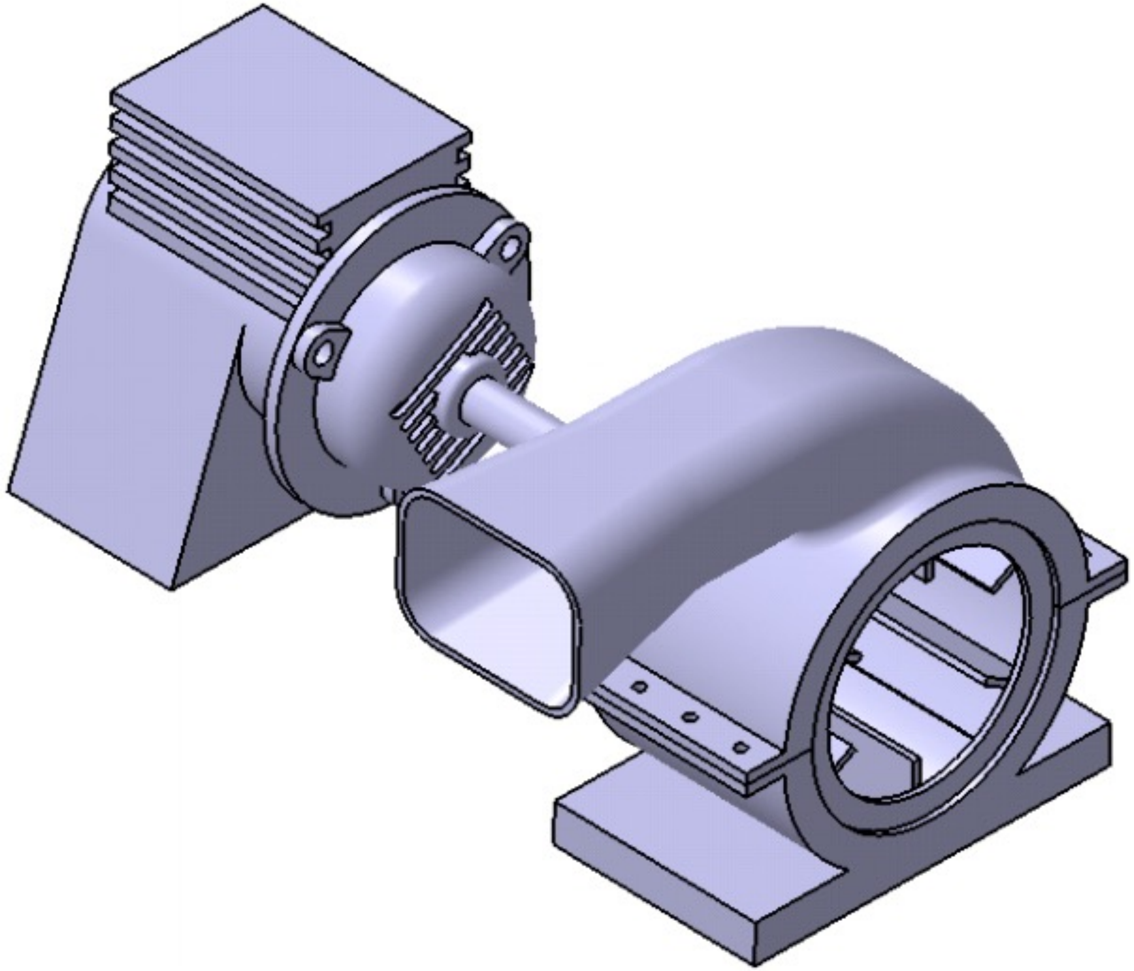
Assembly modeling allows the integration of design and manufacturing to production planning and control.



Assembly modeling

In an assembly model, components are brought together to define a larger, more complex product representation.

Assembly modeling is a tool that allows and facilitates the collaboration among designers, analysis people, manufacturing people, and others, to insure their assembly works together.



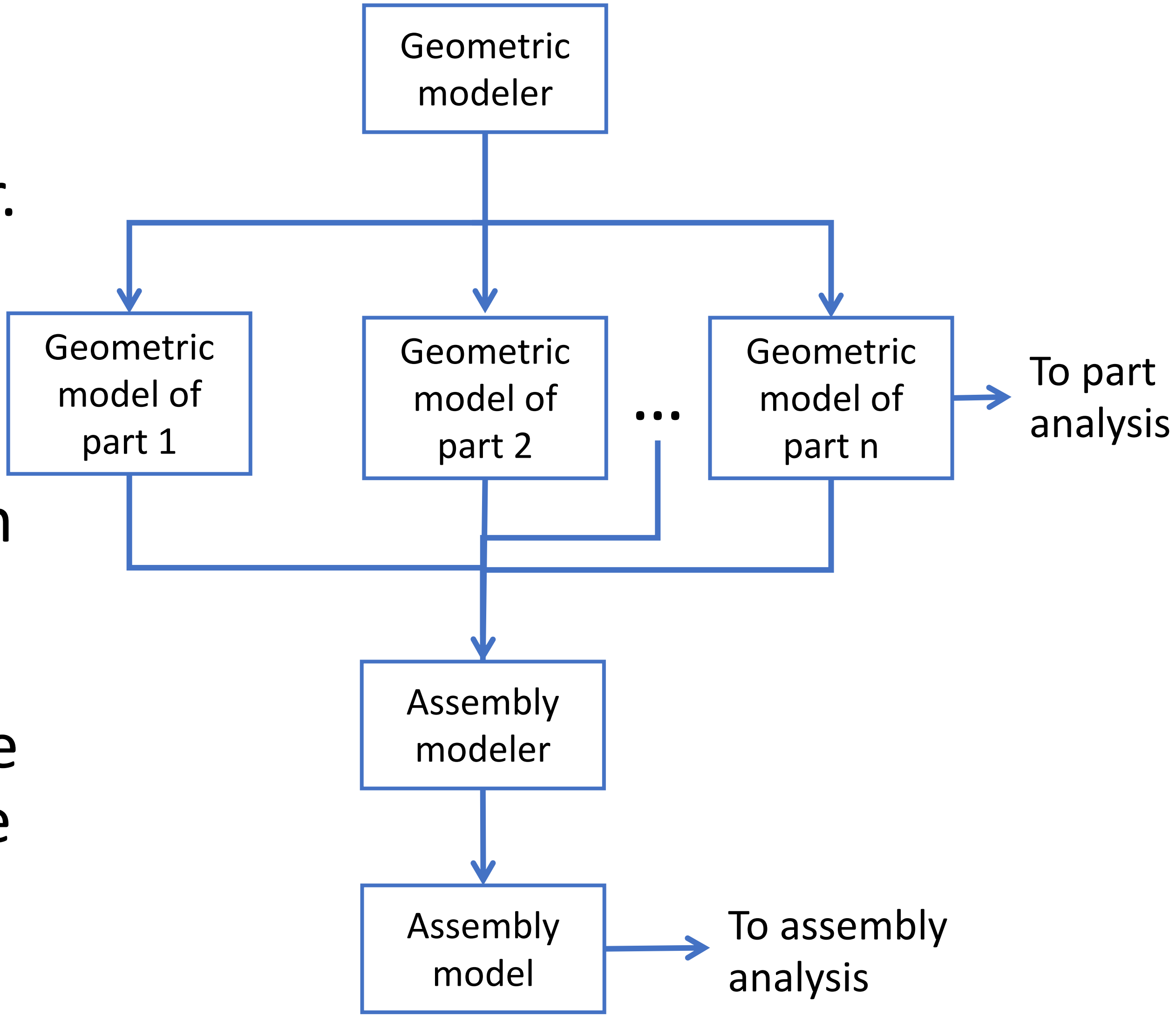
Assembly modelers

Assembly modelers can be thought of as more advanced geometric modelers where the data structure is extended to allow representation and manipulation of hierarchical relationships and mating conditions that exist between components in an assembly.

Geometric and Assembly Modelers

The geometric modeler acts as a front end to the assembly modeler. Individual parts may be modeled using the geometric modeler.

These models may be analyzed individually at this stage. After each part has been analyzed and optimized, the designer would use the assembly modeler to synthesize an assembly model and analyze the entire system.



Assembly modeling

Assembly modeling used for

- Creation of orthographic assembly drawings.
- Creation of exploded assemblies.
- Facilitate packaging
- Perform interference and clearance checks

Definitions

Assembly : is a collection of pointers to piece parts and/or subassemblies. An assembly is a part file that contains component objects.

Subassembly : is an assembly that is used as a component object within a higher level assembly. A subassembly contains component objects of its own.

Component object : is the entity that contains and links the pointer from the assembly back to the master component part. A component object can also be a subassembly made up of its own component parts and/or component objects.

Types of Assembly Design Approach

Assemblies modelling in parametric CAD systems often use Bottom-up Design and Top-down Design strategies. There is also the method which is the combination of these two methods.

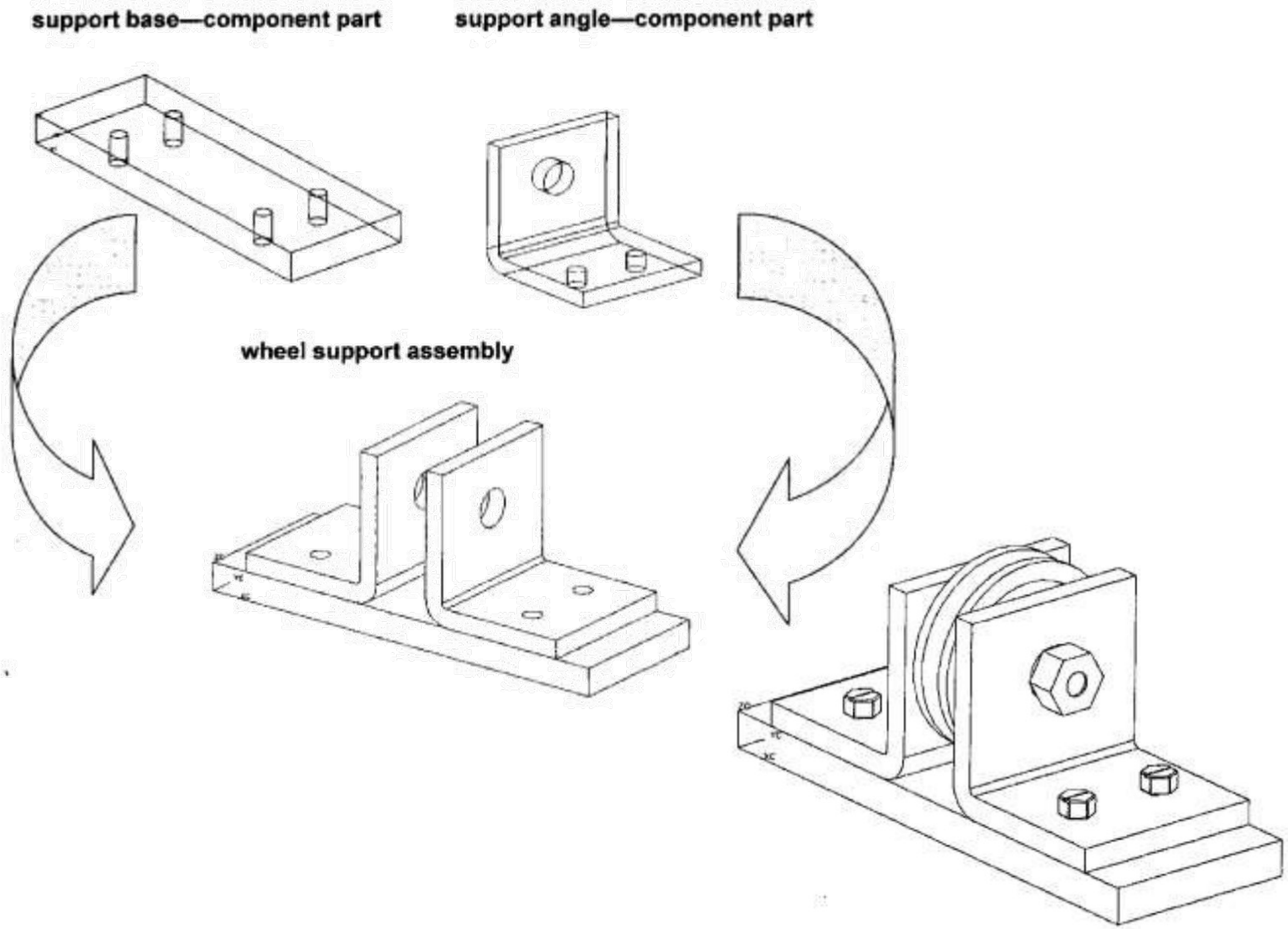
Bottom-up Assembly : is the most preferred approach for creating assembly models.

Top-down Assembly: Adopting the top-down design approach gives the user the distinctive advantage of using the geometry of one component to define the geometry of the other.

Bottom-up Assembly Approach

The individual parts a created independently, inserted into the assembly, and located and oriented (using the mating conditions) as required by the design.

The bottom-up-approach is the preferred technique if the parts have already been created (off the shelf).



Top-down Assembly Approach

In this approach, the assembly file is created first with an assembly layout sketch.

The parts are made in the assembly file or the concept drawing of the parts are inserted and finalized in the assembly file.

The final geometry of the parts have not been defined before bringing them into the assembly file.

This design approach is highly preferred, while working on a conceptual design or a tool design where the reference of previously created parts is required to develop a new part.

Mixed Assembly Approach

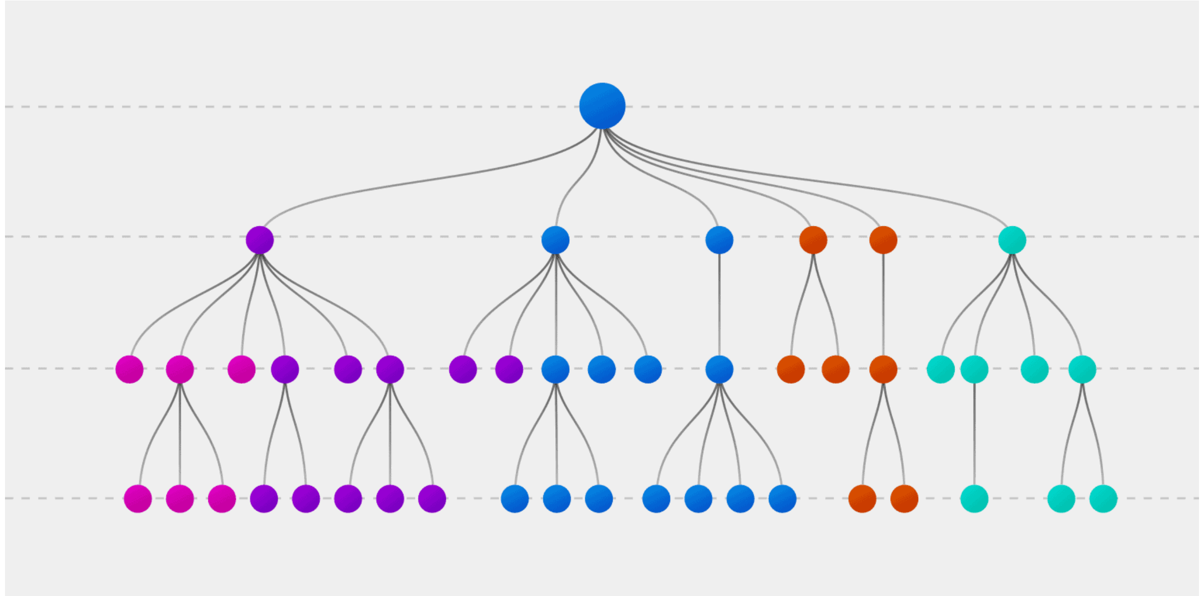
The vast majority of the designed assemblies consist two modelling strategies, bottom-up technique and top-down technique. Generally, most of the assemblies are defined of already existing components.

New part is designed in the case when design assumptions are changed or when the project needs to have some design changes.

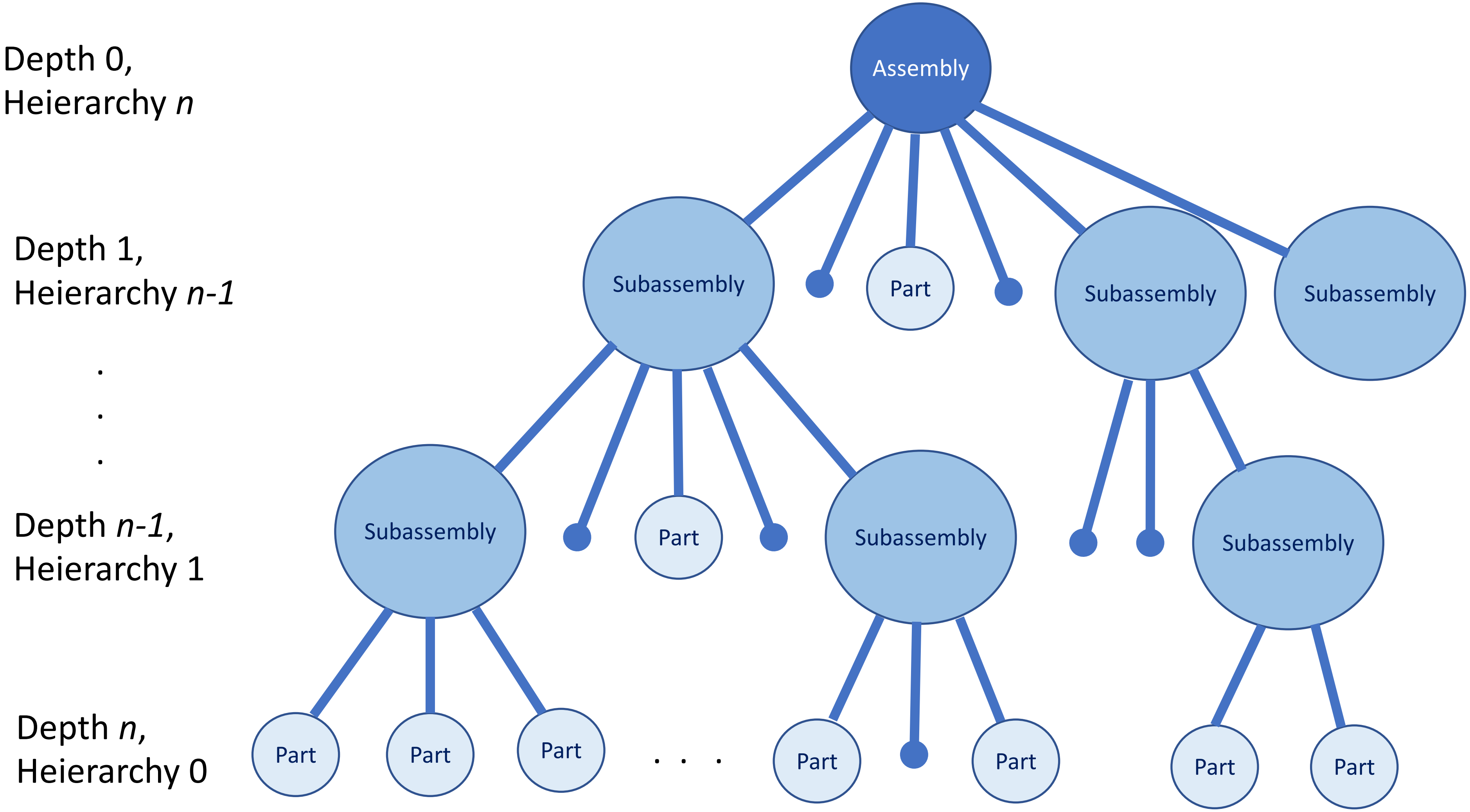
Assembly tree

The assembly tree, shown in the Explorer window, displays all the assemblies and solids in the model.

Each assembly contains all its components and the relationships between the components.



Assembly tree



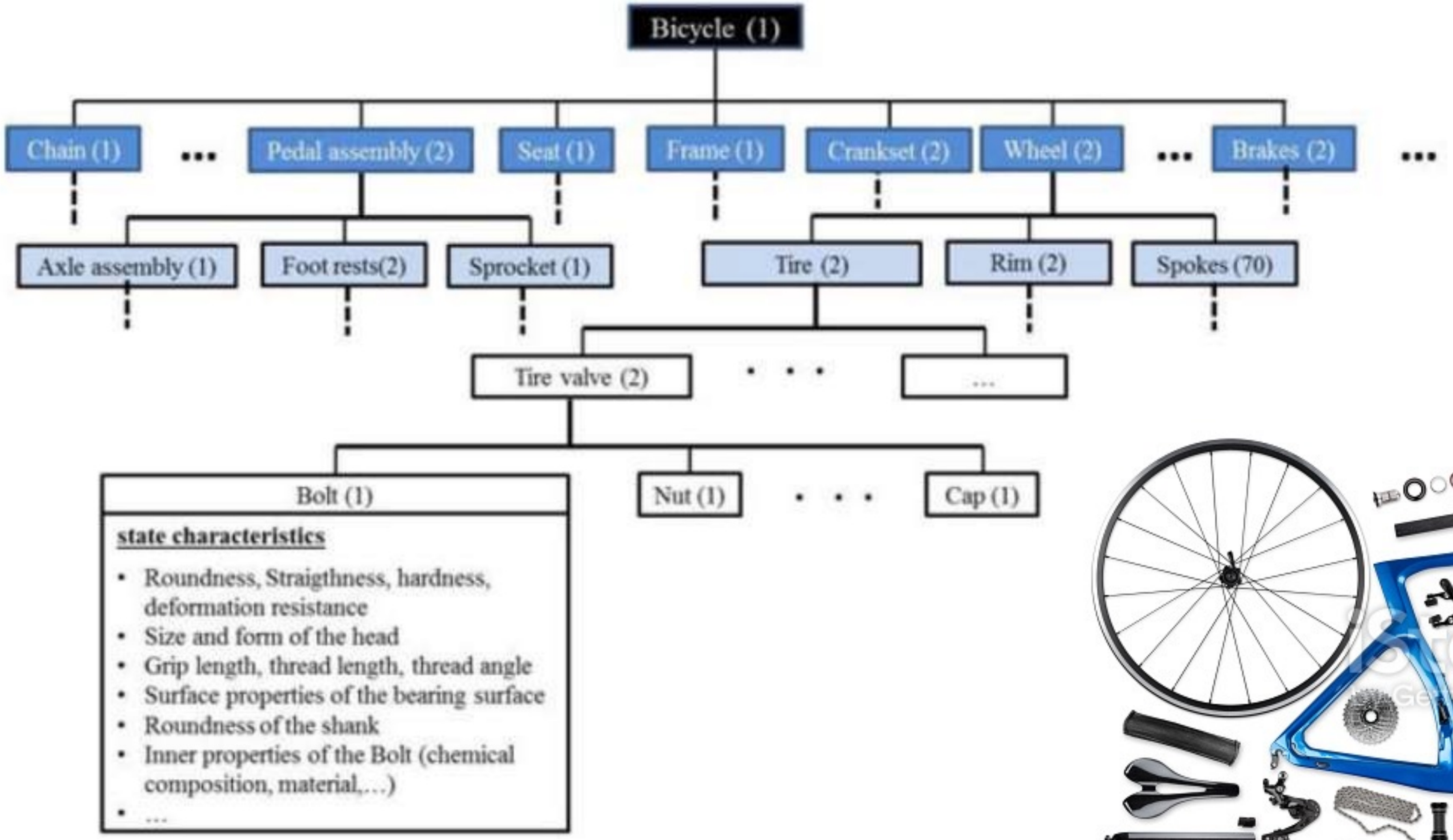
Assembly tree

Assembly tree explodes the overall assembly into subassemblies and parts, as well as illustrates where within the tree structure the various parts and subassemblies are connected or attached.

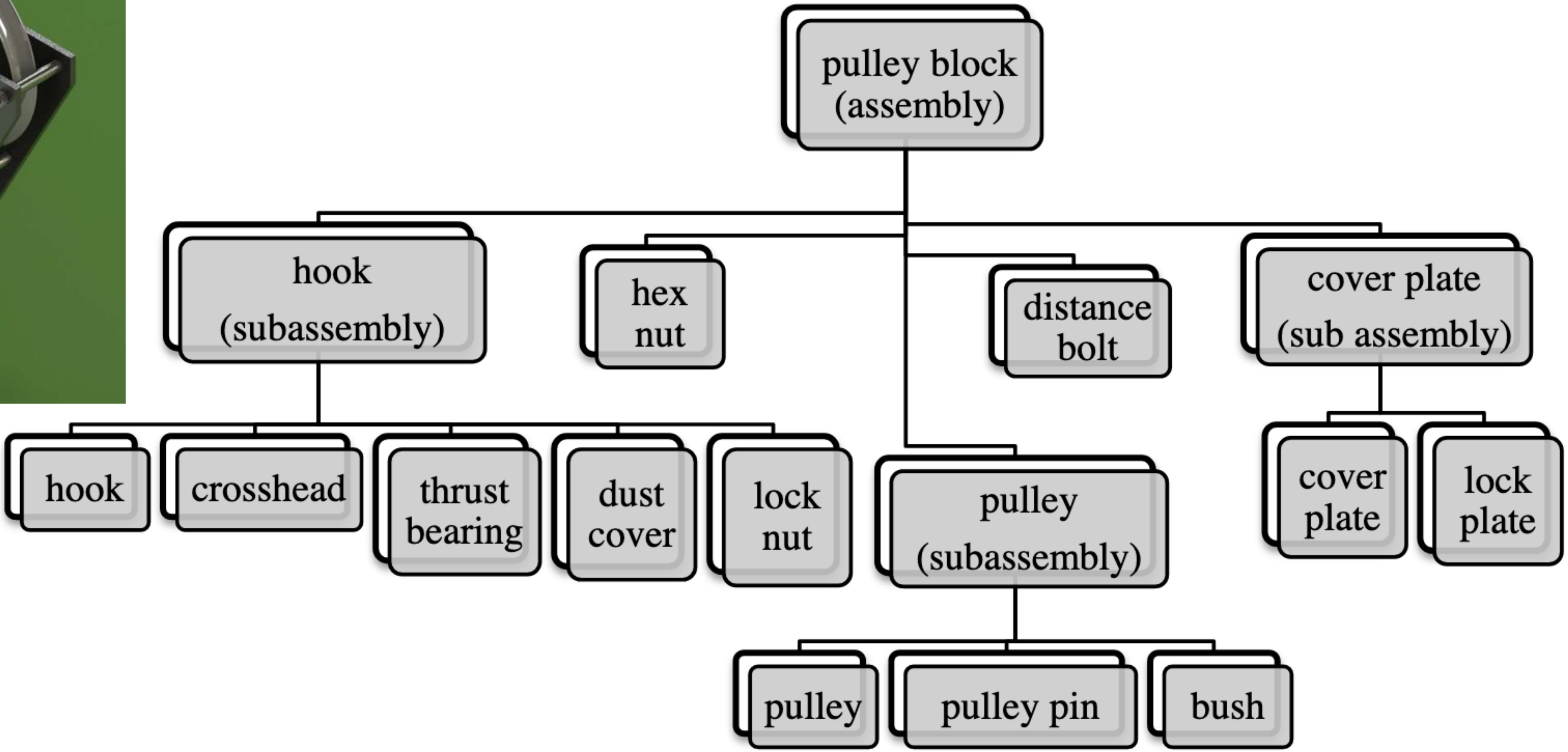
Depth 0: we have the overall assembly.

Depth 1: shows how the major subassemblies and parts fit into the overall assembly.

Assembly tree : bicycle



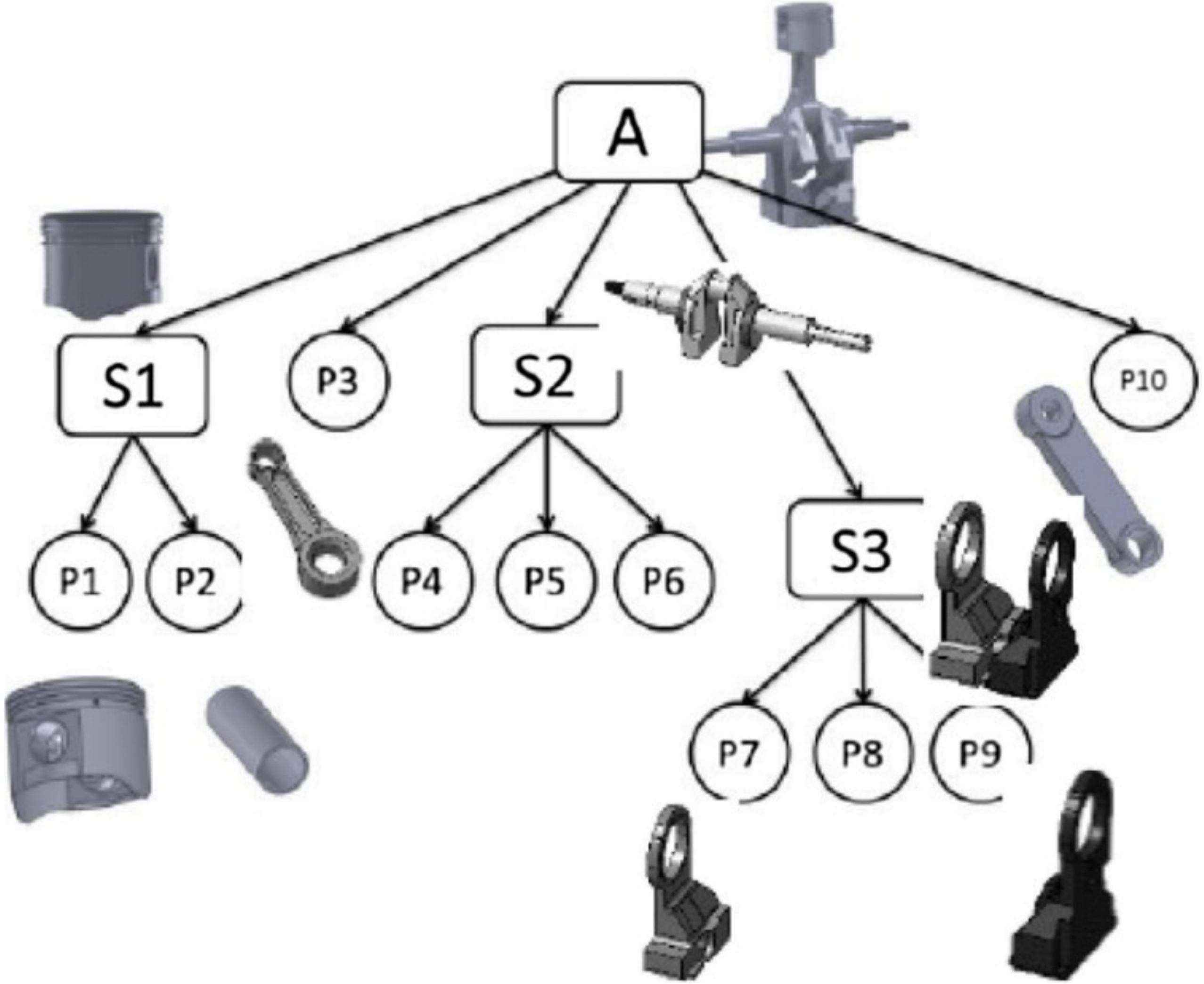
Assembly tree : pulley block



Structural layer

The structural layer of the Enriched Assembly Model (EAM) encodes the hierarchical assembly structure of the CAD model as specified by the designer.

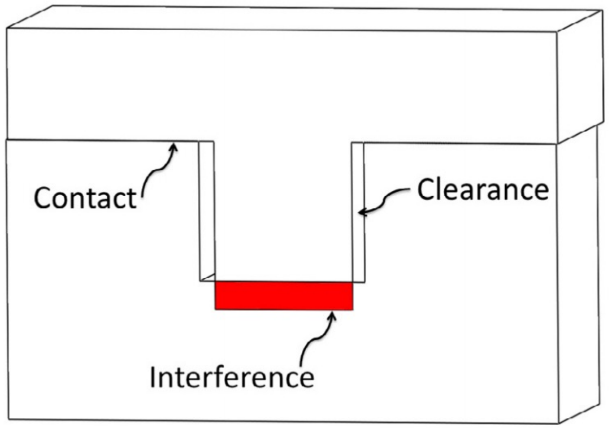
This partition, even if it is driven by some standard rules, is not unique and reveals the designer intents.



K.Lupinetti, F.Giannini, M.Monti, J-P. Pernot, Multi-criteria retrieval of CAD assembly models, J. of Computational Design & Eng. 5 (2018), pp.41-53

Possible relationships between parts

The possible relationships between two parts can be grouped into contact, interference, and clearance.



Contact : Two parts are in contact, if they touch along low-level geometric entities such as surfaces, curves or points without any shared volume.

Interference : Two parts define an interference, if a common volume exists between them. Most of the time, this configuration does not exist between two real objects

Clearance : occurs when the distance between two surfaces of two parts is meaningful for the considered assembly, i.e. it is a small non-null distance between two parts in the assembly.

DOF values according to the surface type

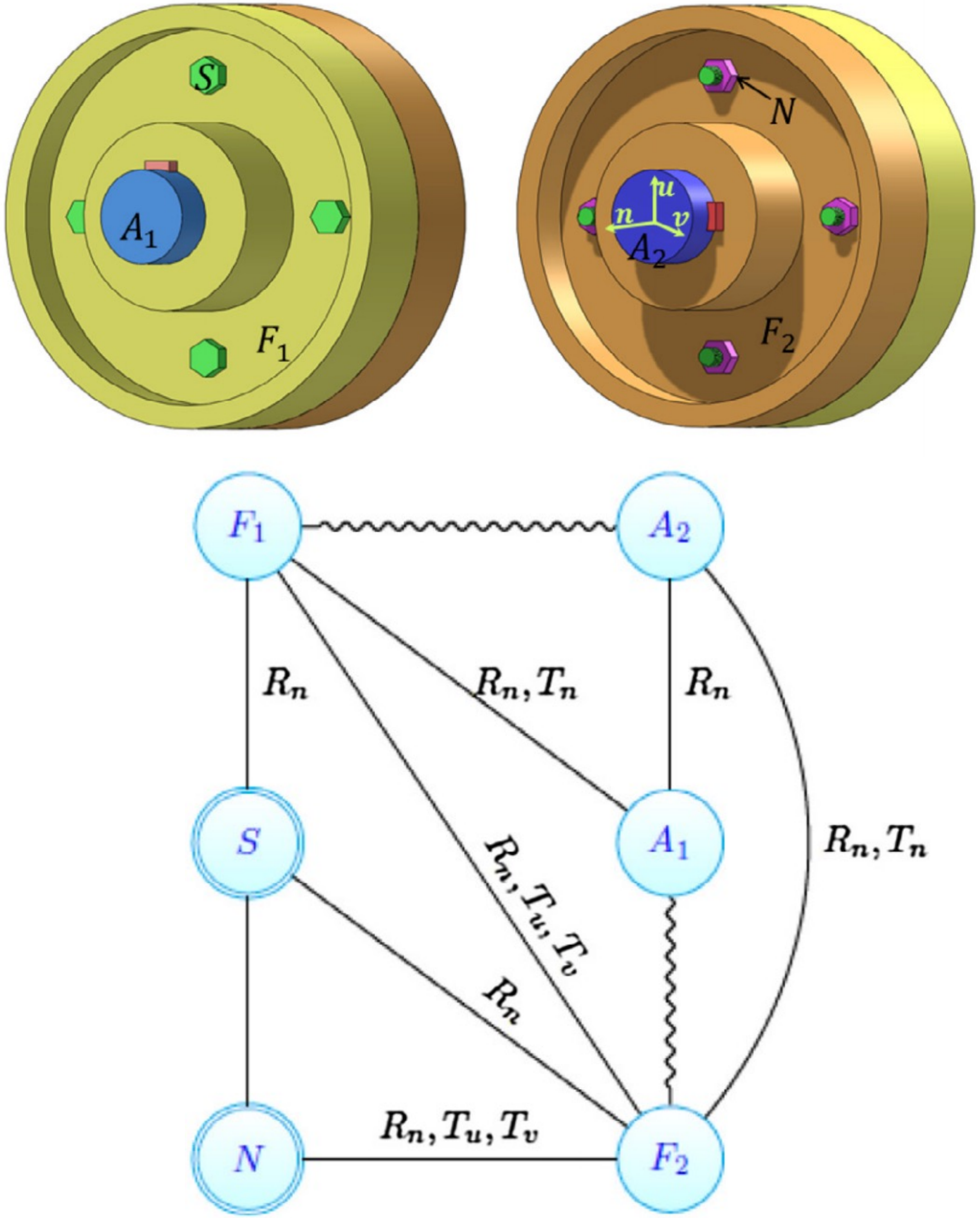
Type	Parameters	DOF
Planar	n normal	R_n, T_u and T_v, where u and v are orthogonal to n
Cylindrical	u axis O origin	R_{u+O} and T_u
Conical	u axis O origin	R_{u+O}
Spherical	O origin	R_{u+o}, R_{v+o} and R_{n+o}
Toroidal	u axis O origin	R_{u+O}

where R indicates a rotation, T a translation, the subscripts u, v and n the vector along which the rotations/translations are allowed.

Example

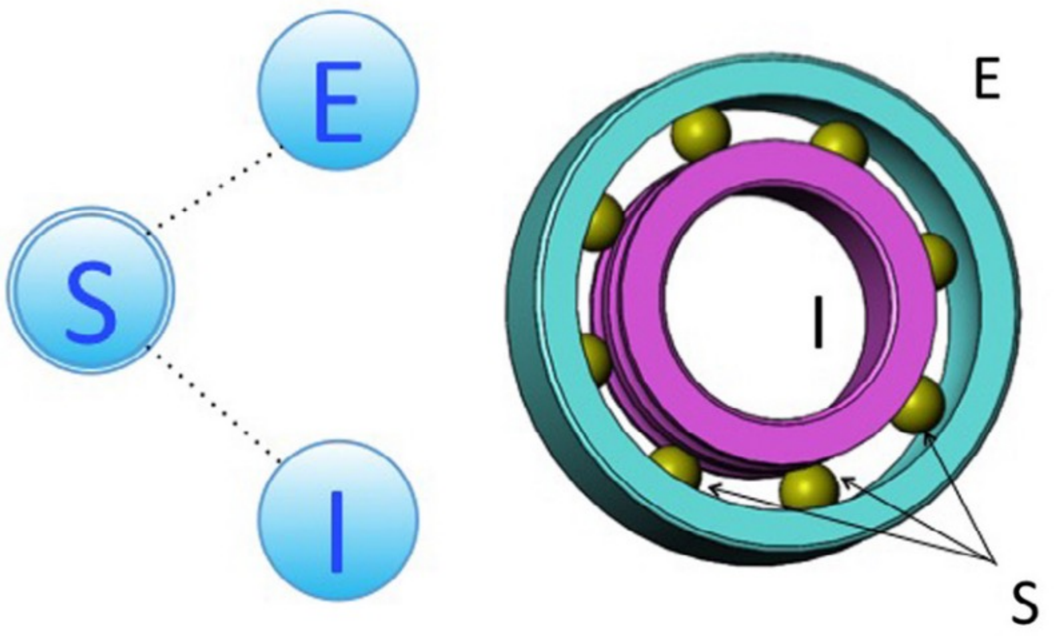
The simply-circled nodes are associated with parts, while the double-circled nodes (S and N) are associated with a set of parts belonging to circular rotational patterns.

The straight arc connects two components, which are in face contact. The wavy arcs indicate a line contact and according to the description of the interface layer.



Example

The part of bearing for the nodes E and I, and sphere like for the node S. For the node S, the characteristic of belonging to a circular pattern is also specified.

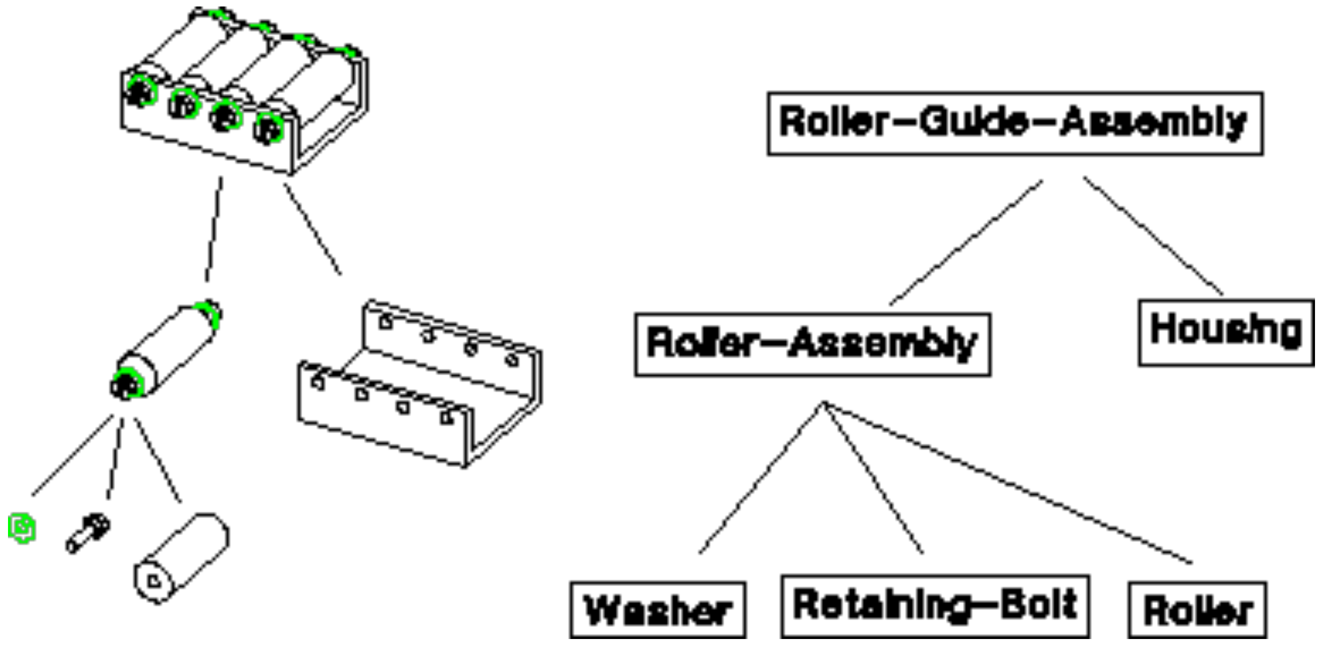


Assembly hierarchy

An assembly is a modeling entity that combines parts into a hierarchical product structure.

An assembly hierarchy is a way to organize the collection of parts.

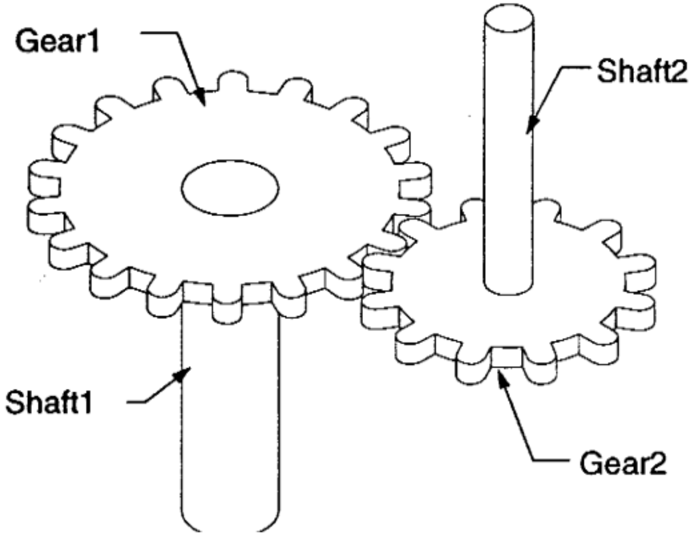
A part contains geometry definition and other attributes such as color and mass properties.

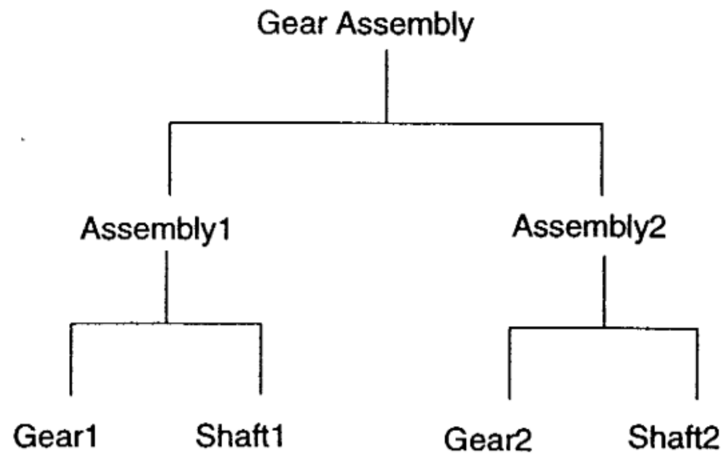


Assembly hierarchy

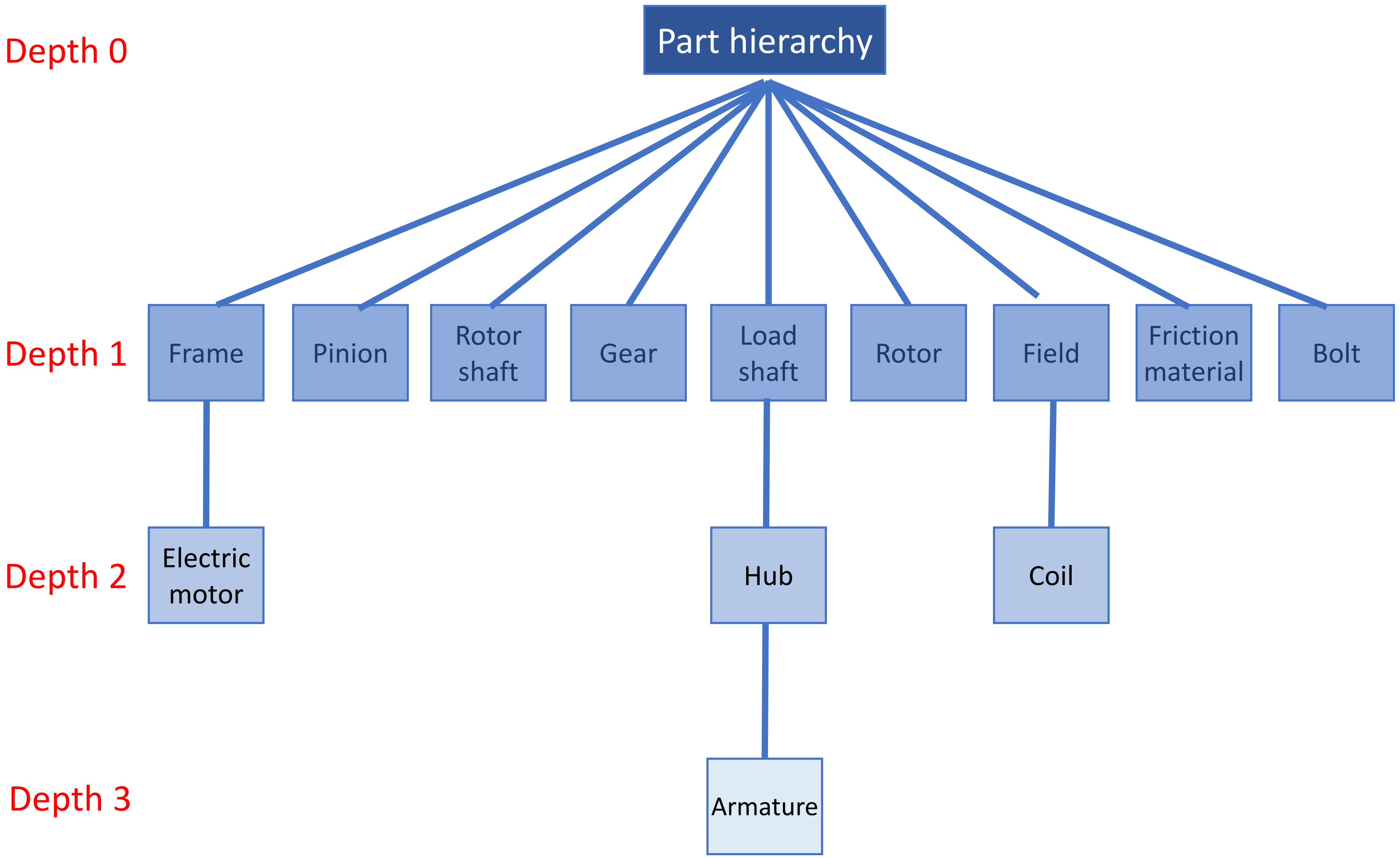
The assembly hierarchy defines relationships of parts to each other. It is easier to work with assembly models if they are organized in a logical manner.

An assembly can usually be thought of as composed of several smaller subassemblies, each of which in turn may consist of other subassemblies or individual components.





Example : electric clutch (Part hierarchy)



Assembly mating conditions

Basic mates	Advanced mates	Mechanical mates
Coincident	Offset	Cam
Concentric	Surface intersecting an edge	Hinge
Coplanar	Edge intersecting a point	Gear
Tangent	Angles of surfaces/planes to each other	Rack pinion
Parallel	Symmetry	Screw
Perpendicular	Path	Universal joint
Lock	Relationship of a geometry to a coordinate system	
Distance		

Constraints of components

The constraints are the basic element of assemblies designing. They make geometrical correlations between components in the assembly. Each unrelated component in the assembly has six degrees of freedom.

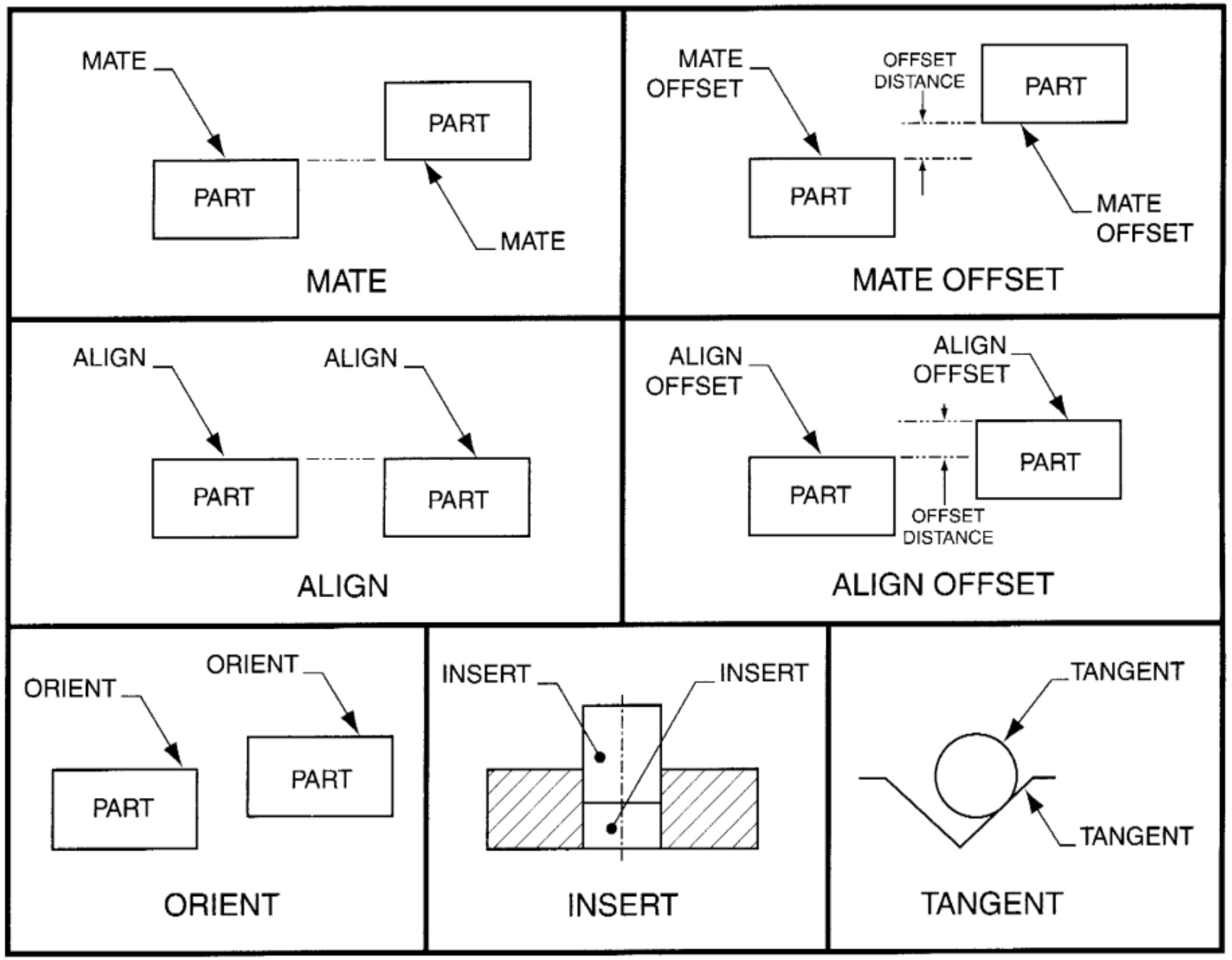
Translation – movement along X, Y, and Z axis.
Rotation – rotate about X, Y, and Z axis

The elements associated in the constraint can be: planar, cylindrical and conical faces, planes, axes, origins, edges of components, elements of sketches, vertices or sketch points.

Assembly constraints

Assembly constraints can be used to create permanent relationships between parts.

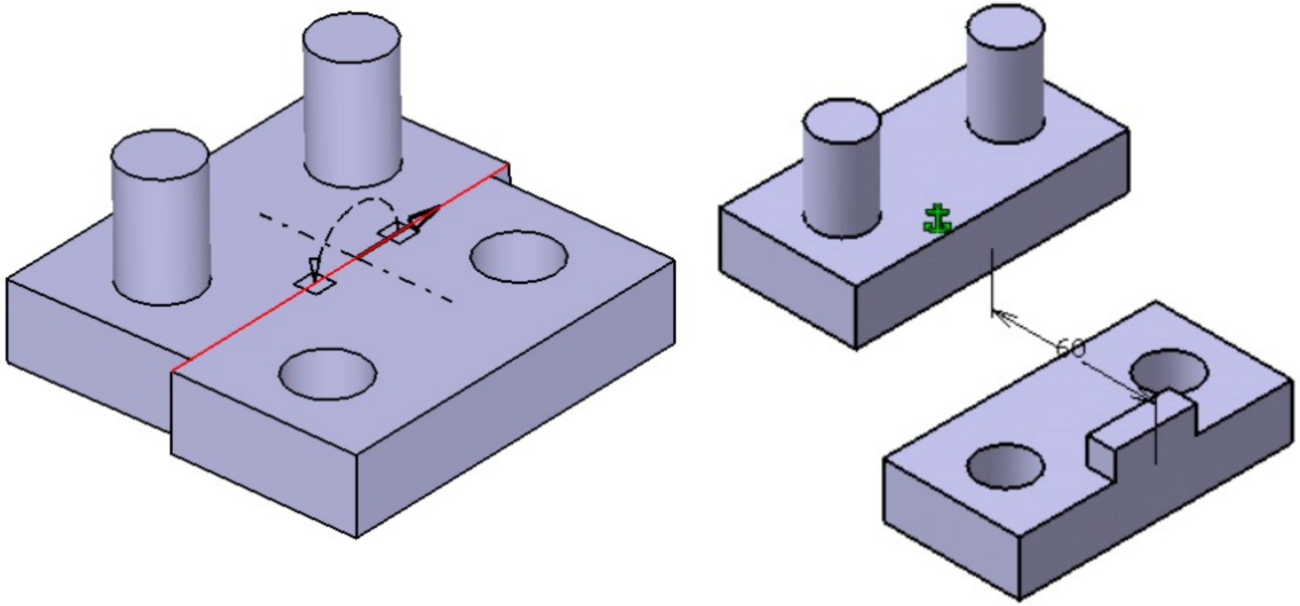
They use the same commands as 2D constraints.



Assembly constraints – mate & mate Offset

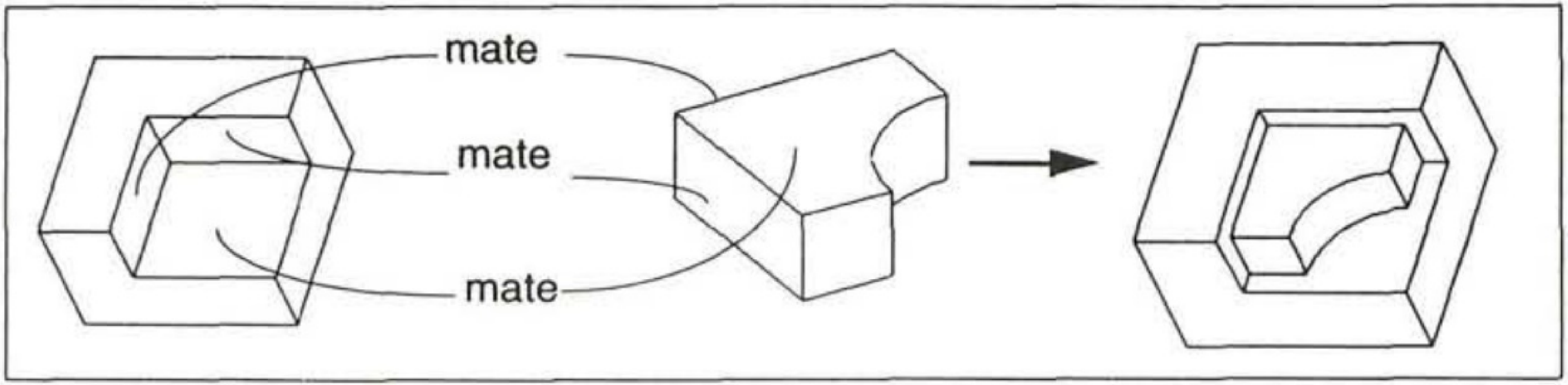
The Mate constraint type is used to place two surfaces coplanar. Any datum plane, part plane, or planar surface can be used. Selected surface faces are placed along a common plane but do not actually have to touch.

When a datum plane is selected, since a datum plane has no defined thickness, CAD software provides the option of selecting either the positive side or negative side of the datum plane.



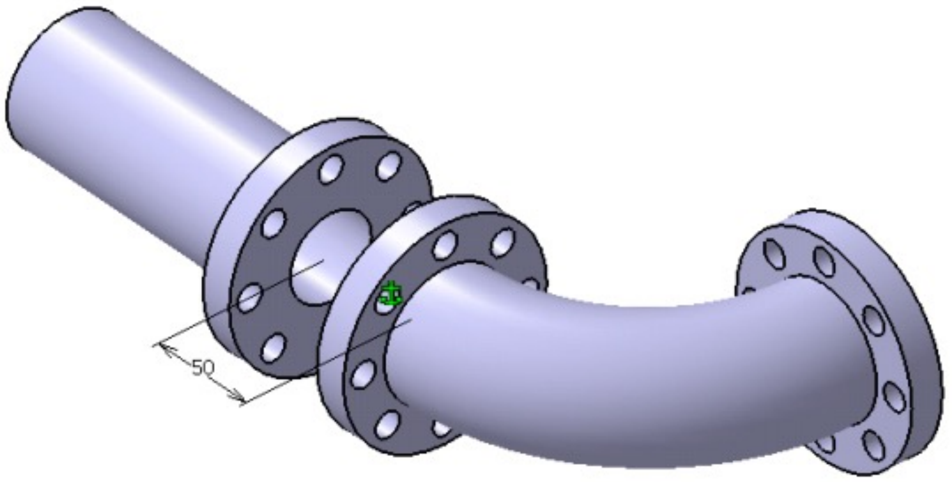
Assembly constraints – mate & mate offset

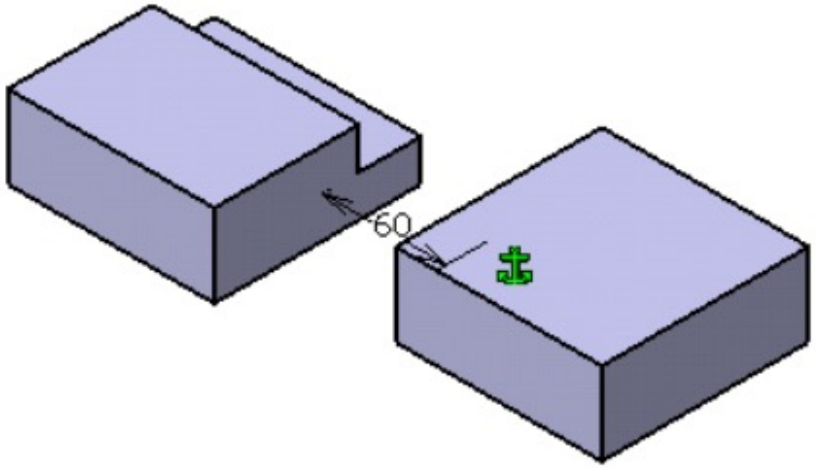
The Mate Offset constraint type is similar to the Mate constraint type. Unlike the Mate type, the Mate Offset constraint places a user-specified offset distance between selected features.



Assembly constraints – align & align offset

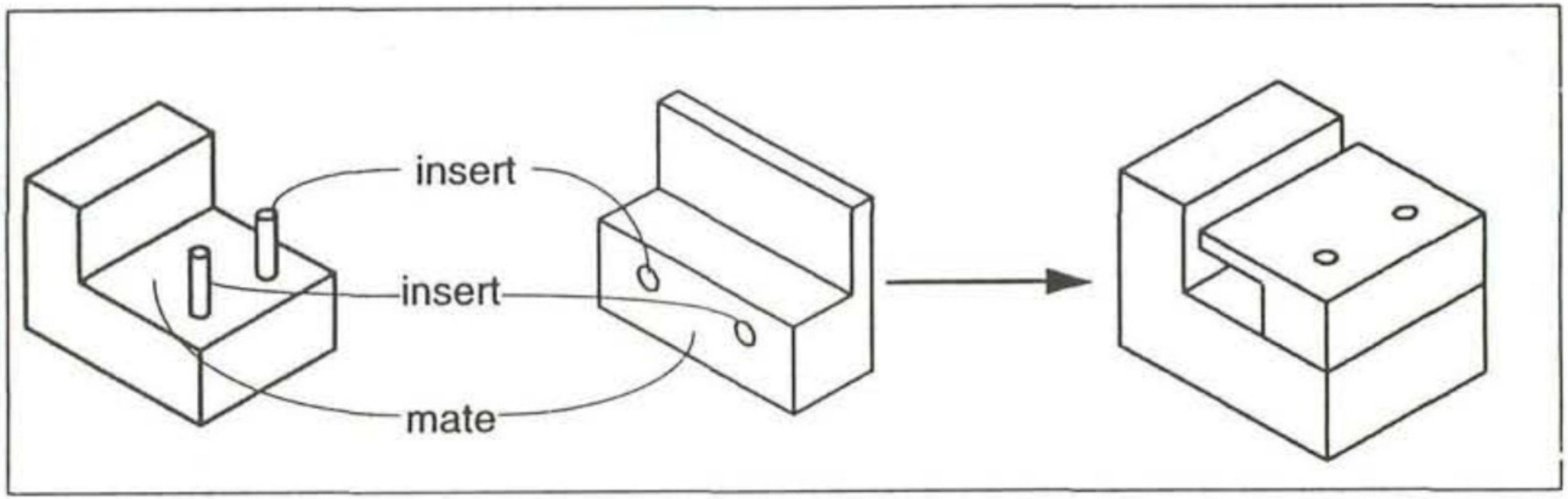
The align constraint type is used to place two surfaces coplanar and facing in the same direction. Like the mate constraint, the surfaces do not have to touch. In addition, the align constraint type is used to align axes, edges, curves and points.

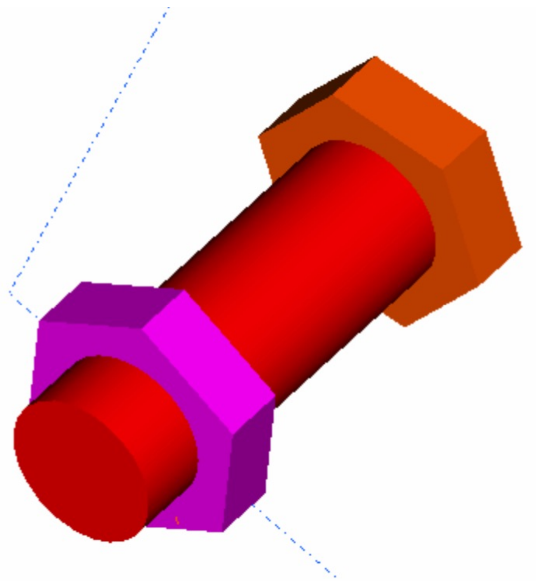




Assembly constraints - Insert

The insert constraint type makes the axes of two revolved features coincident. The user is required to select the surface of each feature.

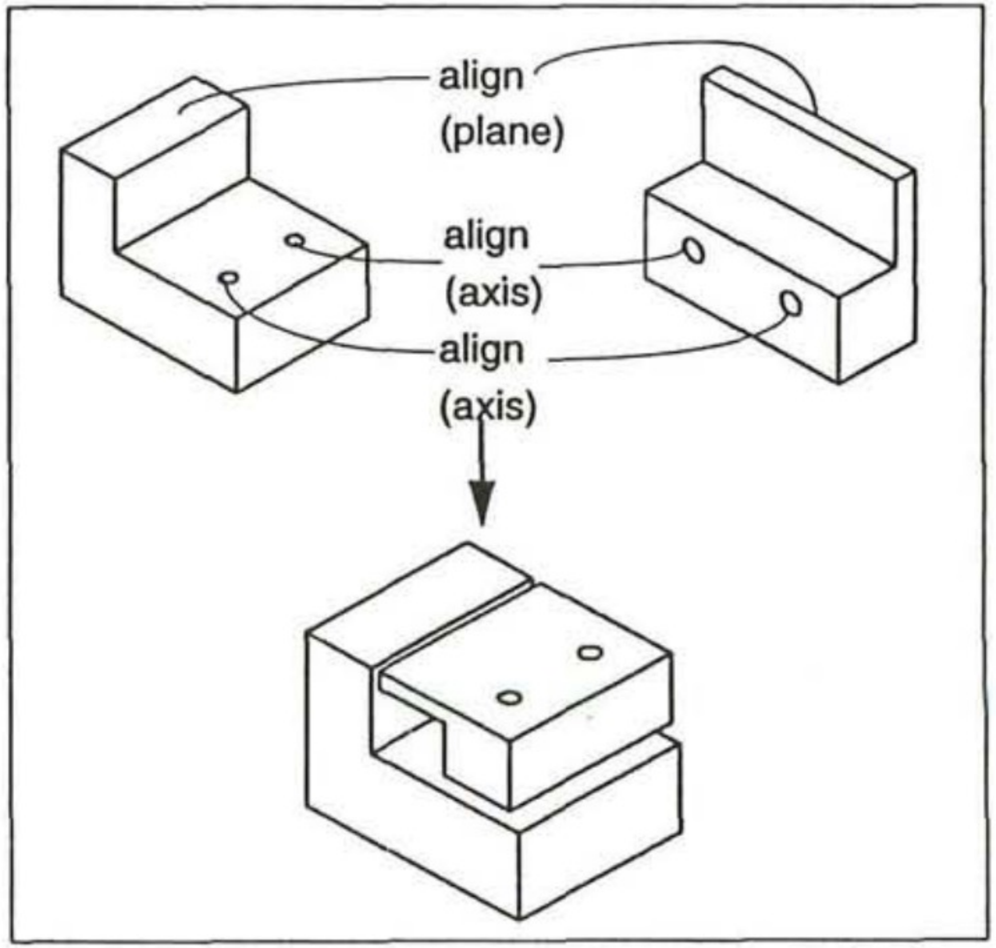




Assembly constraints – align & align offset

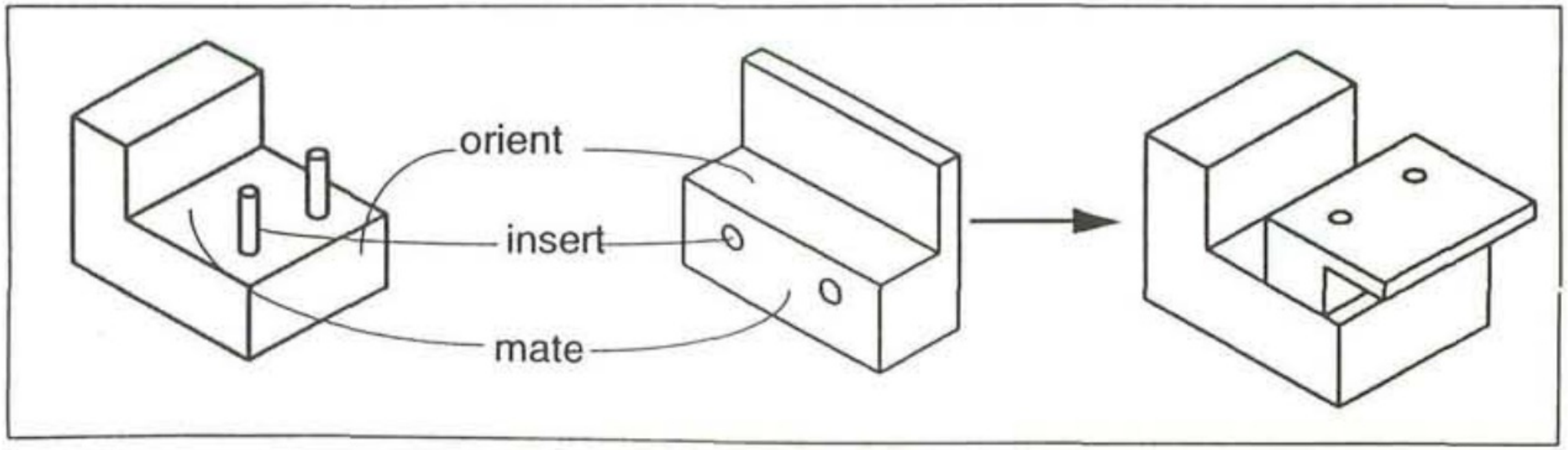
The align offset constraint option is used to align two surfaces with a user-specified offset distance between each surface.

The value can be either positive or negative.



Assembly constraints - Orient

Like the align constraint type, the orient constraint type orients two surfaces facing in the same direction. Unlike align, the two selected surfaces are not coplanar and no offset distance is specified.



Assembly constraints - Tangent

The tangent constraint type makes a cylindrical surface tangent to another surface. The user is required to select the surface of each feature.

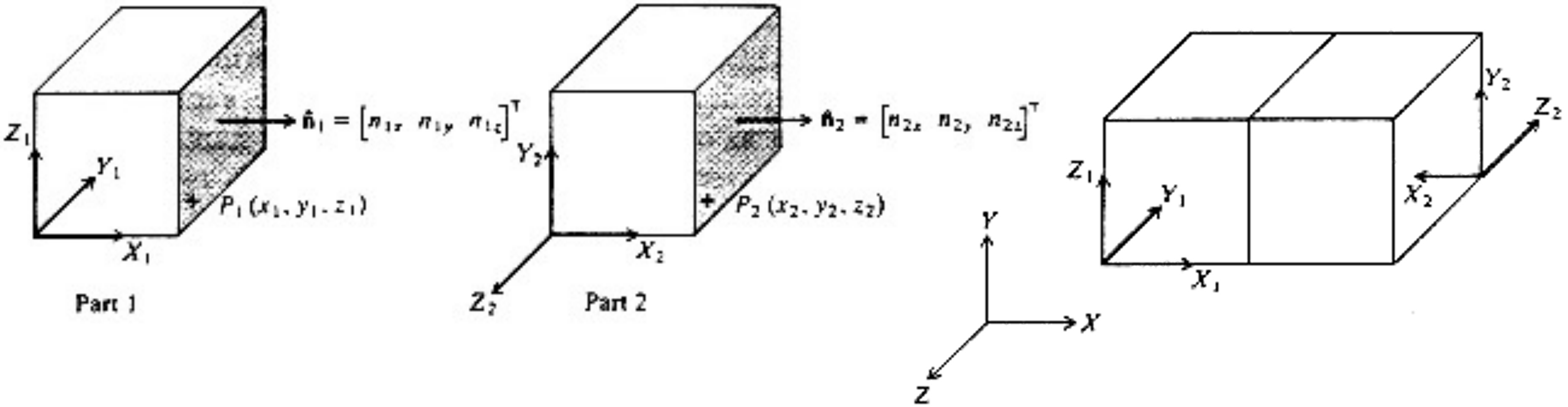
Positioning Parts in an Assembly

Parts can be positioned by translating and rotating them into the right locations. This requires careful measurement of relative locations, knowledge of coordinate systems, and entry of numerical values. If position or dimensions of one part change, this has to be redone.

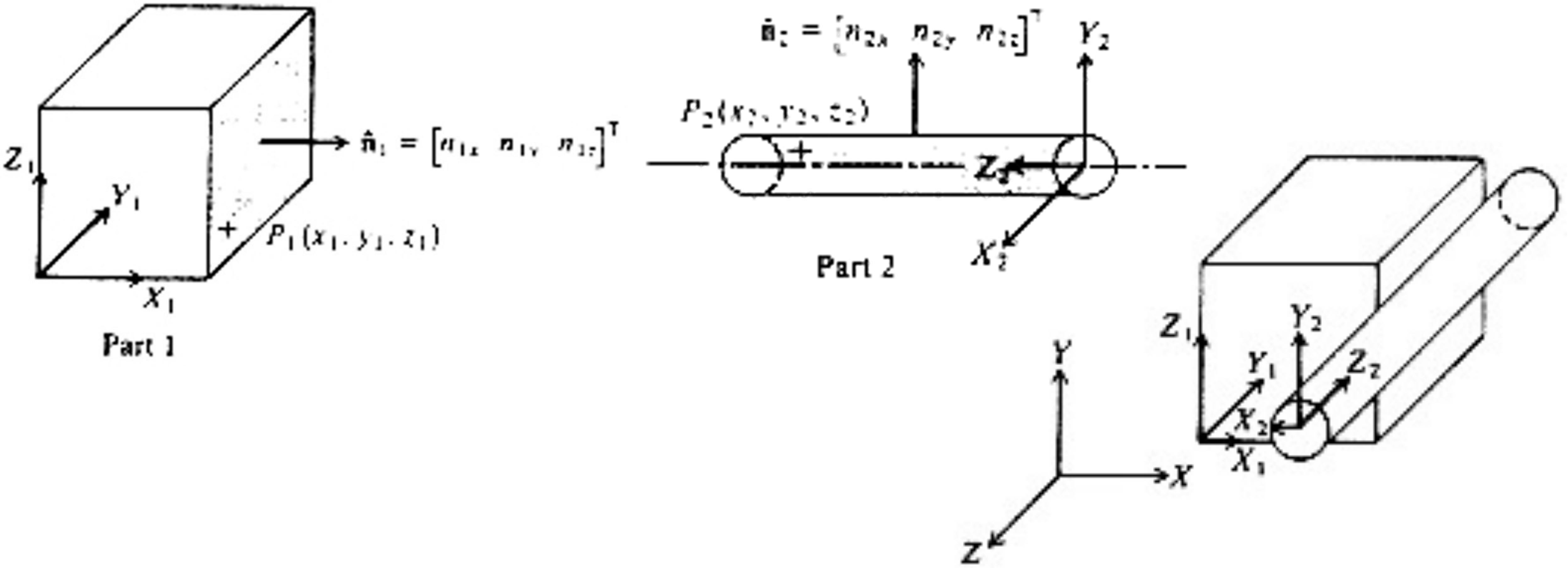
Mating feature types:

- Against : two normal vectors are in against directions
- Fits : between two cylinders: center lines are concentric
- Contact : requires two points correspond
- Coplanar : two normal vectors are parallel

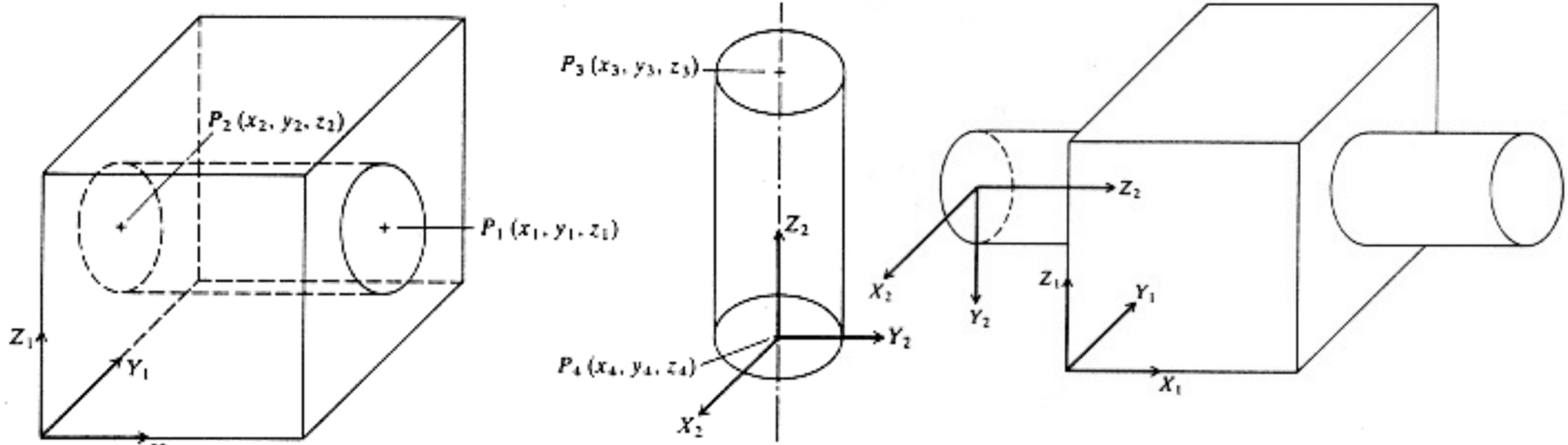
Positioning Parts in an Assembly
Against between two planar faces



Positioning Parts in an Assembly
Against between a planar face and a cylindrical face



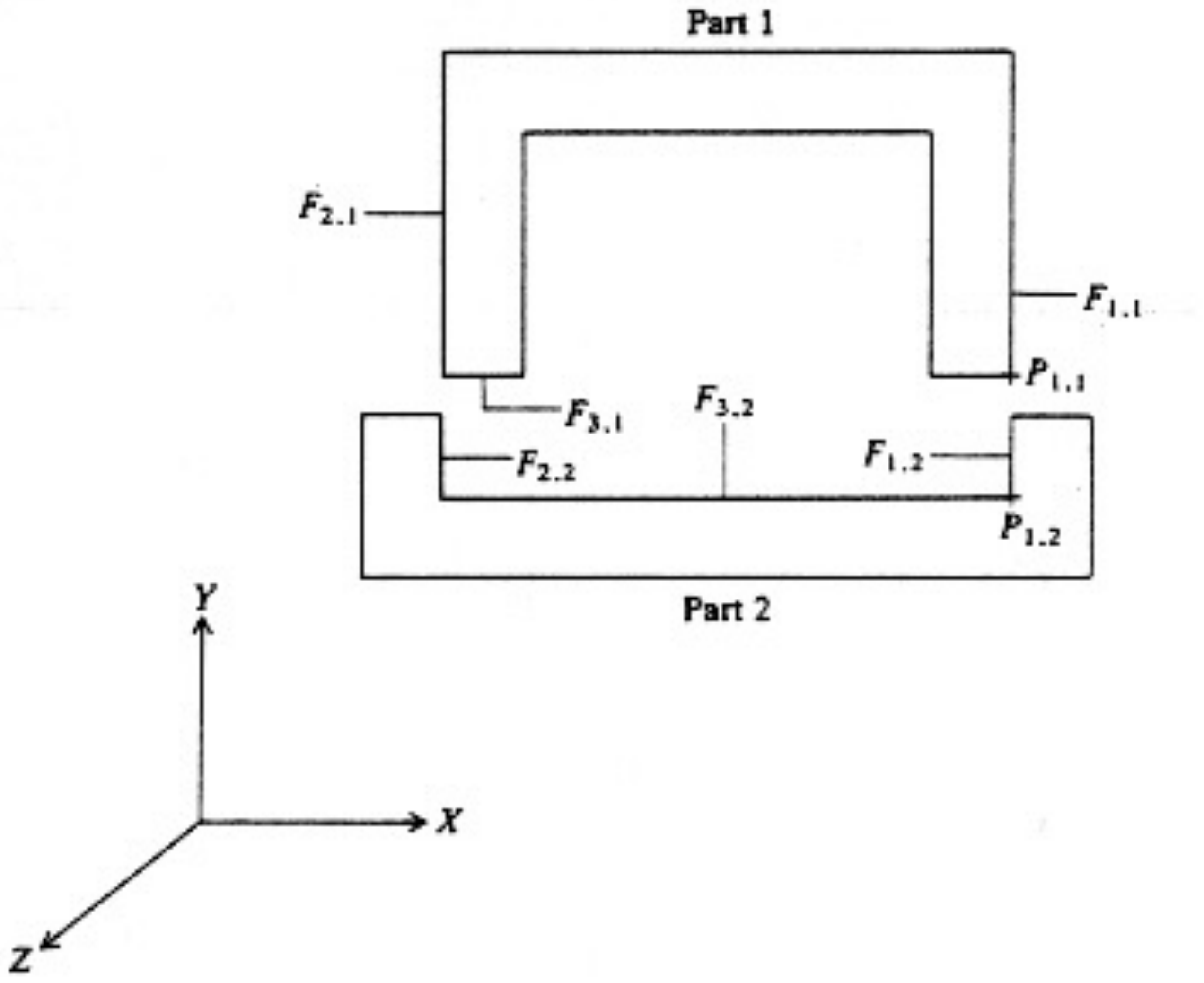
Positioning Parts in an Assembly Fits



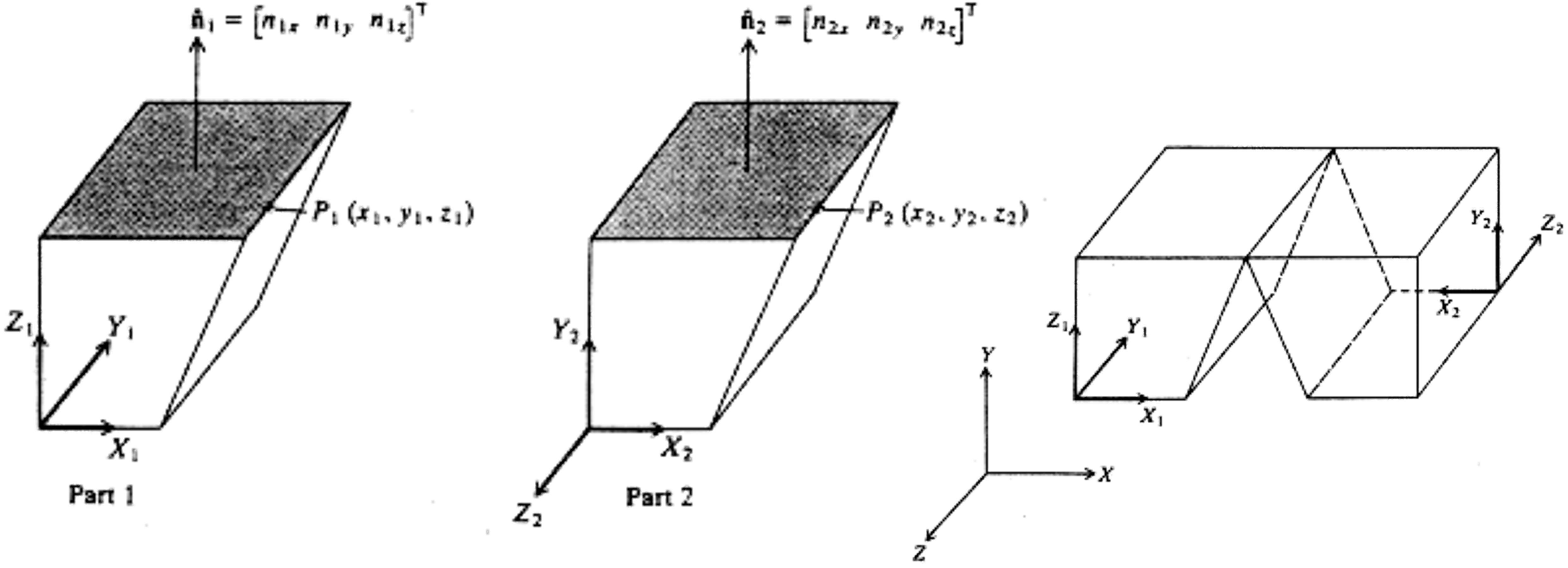
Hole

Shaft

Positioning Parts in an Assembly Contact



Positioning Parts in an Assembly
Coplanar



Basic Properties of Transforms

The 4 x 4 matrix transformation permits representation of both the relative position of two objects and their relative orientation.

$$T = \begin{bmatrix} R & p \\ 0^T & 1 \end{bmatrix}$$

p : a 3x3 displacement vector indicationg the position of the new frame relative to the old one,

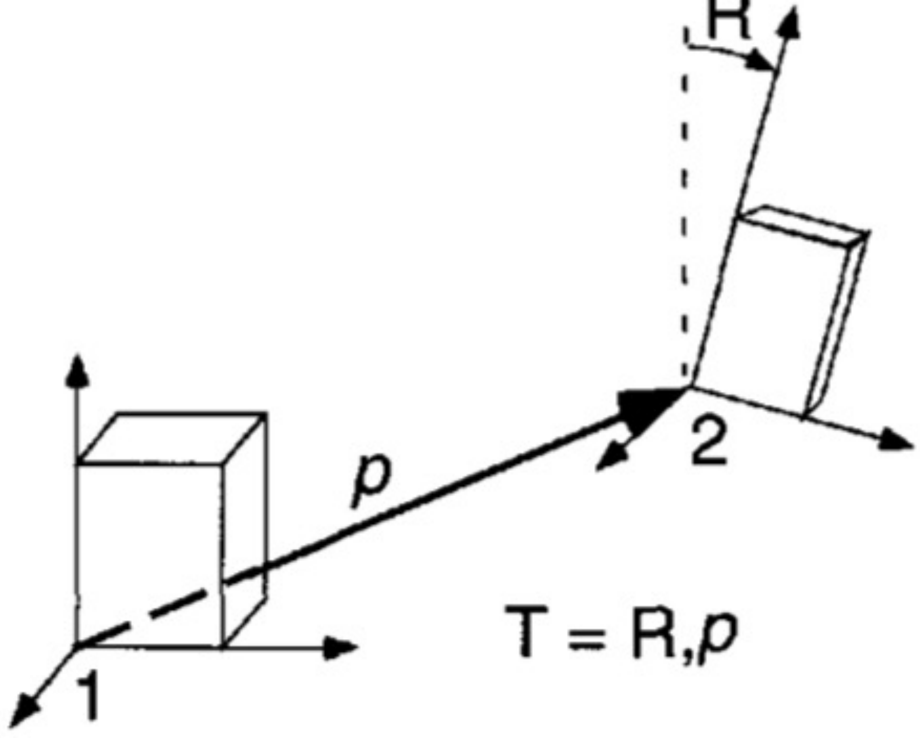
R : a 3x3 rotation matrix indicating the orientation of the new frame relative to the old one.

Schematic Representation of a Transform

The transform T contains a translational part represented by vector p and a rotational part represented by matrix $R.$

Vector p is expressed in the coordinates of frame 1.

Matrix R rotates frame 1 into frame 2.



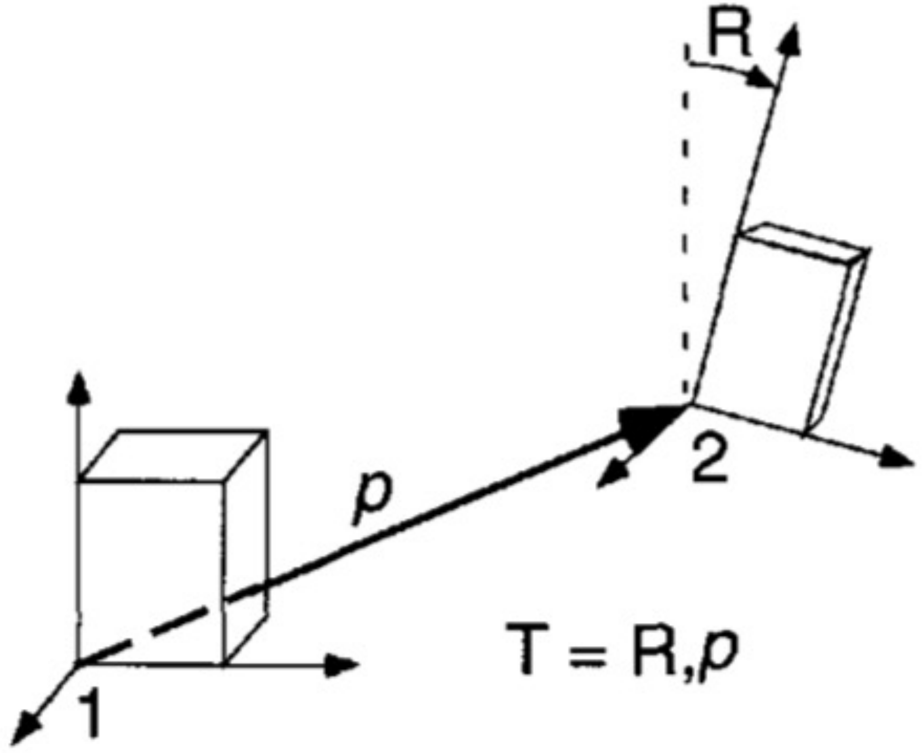
Schematic Representation of a Transform

On a component-by-component basis, transform T is

$$T = \begin{bmatrix} r_{11} & r_{12} & r_{13} & p_1 \\ r_{21} & r_{22} & r_{23} & p_2 \\ r_{31} & r_{32} & r_{33} & p_3 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

p :is expressed in the coordinates of the original frame and

$r_{i,j}$ are the direction cosines of axis i in frame 1 to axis j in frame 2.



Schematic Representation of a Transform

Transform T can be used to calculate the coordinates of a point in the second coordinate frame in terms of the first coordinate frame.

Then, in general, if q is a vector in the second frame, its coordinates in the first frame are given by q' :

$$q' = \begin{bmatrix} R & p \\ 0^T & 1 \end{bmatrix} \begin{bmatrix} q \\ 1 \end{bmatrix} = Rq + p$$

This says that q' is obtained by rotating q by R and then adding p.

The coordinates of a point are given by

$$p = \begin{bmatrix} x \\ y \\ 1 \end{bmatrix}$$

Schematic Representation of a Transform

Suppose a transform T consists only of matrix R, and suppose that we want to find the coordinates of the end of a unit vector along the *z* axis of the rotated second frame in terms of the unrotated first frame.

$$q' = \begin{bmatrix} R & p \\ 0^T & 1 \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ 1 \\ 1 \end{bmatrix} = \begin{bmatrix} r_{13} \\ r_{23} \\ r_{33} \\ 1 \end{bmatrix}$$

The columns of matrix R tell where the coordinate axes have rotated.

Matrix R

Matrix R can be generated a number of ways. One way is to rotate once about each coordinate axis.

This will generate one elemental rotation matrix.

$$rot(x,\theta) = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\theta & -\sin\theta & 0 \\ 0 & \sin\theta & \cos\theta & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$rot(y,\beta) = \begin{bmatrix} \cos\beta & 0 & \sin\beta & 0 \\ 0 & 1 & 0 & 0 \\ -\sin\beta & 0 & \cos\beta & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$rot(z,\alpha) = \begin{bmatrix} \cos\alpha & -\sin\alpha & 0 & 0 \\ \sin\alpha & \cos\alpha & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Schematic Representation of a Transform

A transform that simply repositions a frame without reorienting it is

$$T_{trans} = \begin{bmatrix} 0 & 0 & 0 & p_x \\ 0 & 0 & 0 & p_y \\ 0 & 0 & 0 & p_z \\ 0 & 0 & 0 & 1 \end{bmatrix} = trans(p_x, p_y, p_z)$$

Schematic Representation of a Transform

A transform T that comprises a translation p_x along x followed by a rotation of 90° about the new (translated) z could then be written

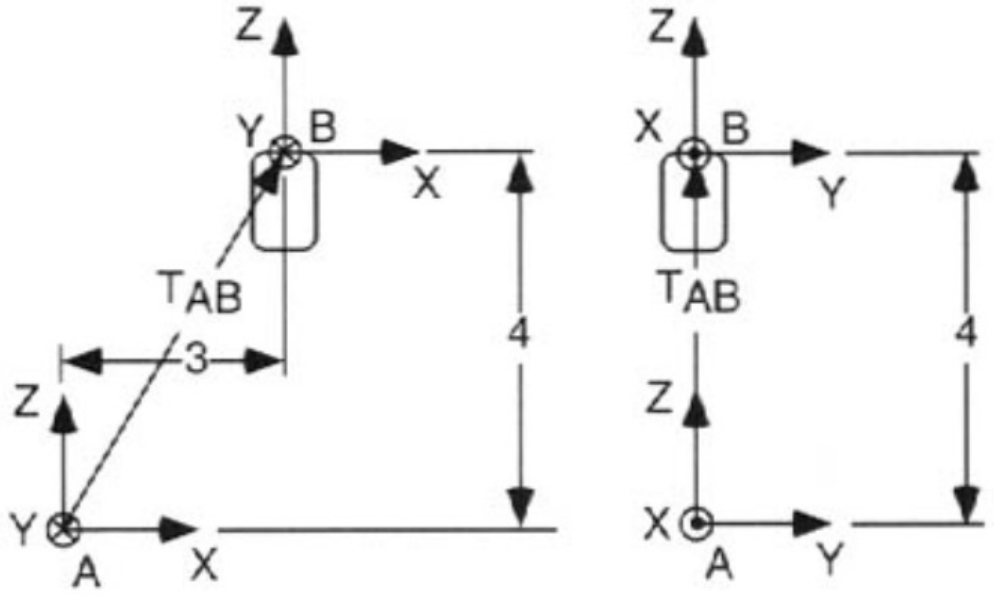
$$T = trans(p_x, 0,0) rot(z, 90)$$

Sample : Transform that Repositions a Feature With- out Rotating It

It shows how to position a feature whose axes align with part center coordinate axes. This feature is a locating pin. Accordingly, the Z axis of the pin's coordinate frame coincides with the pin's centerline.

$$>> T_{AB} = trans(3,0,4)$$

$$T_{AB} = \begin{bmatrix} 1 & 0 & 0 & 3 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 4 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

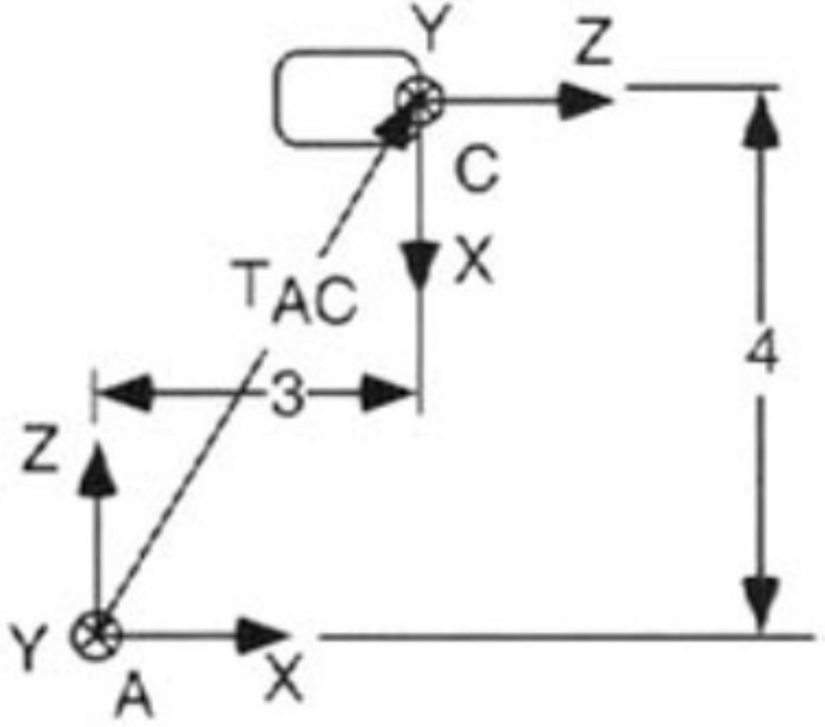


Sample : How to Position and Orient a Feature

It shows how to position a feature and orient it differently from part center coordinate axes.

$$>> T_{AC} = T_{AB}\ roty\ (dtr(90))$$

$$T_{AC} = \begin{bmatrix} 0 & 0 & 1 & 3 \\ 0 & 1 & 0 & 0 \\ -1 & 0 & 0 & 4 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

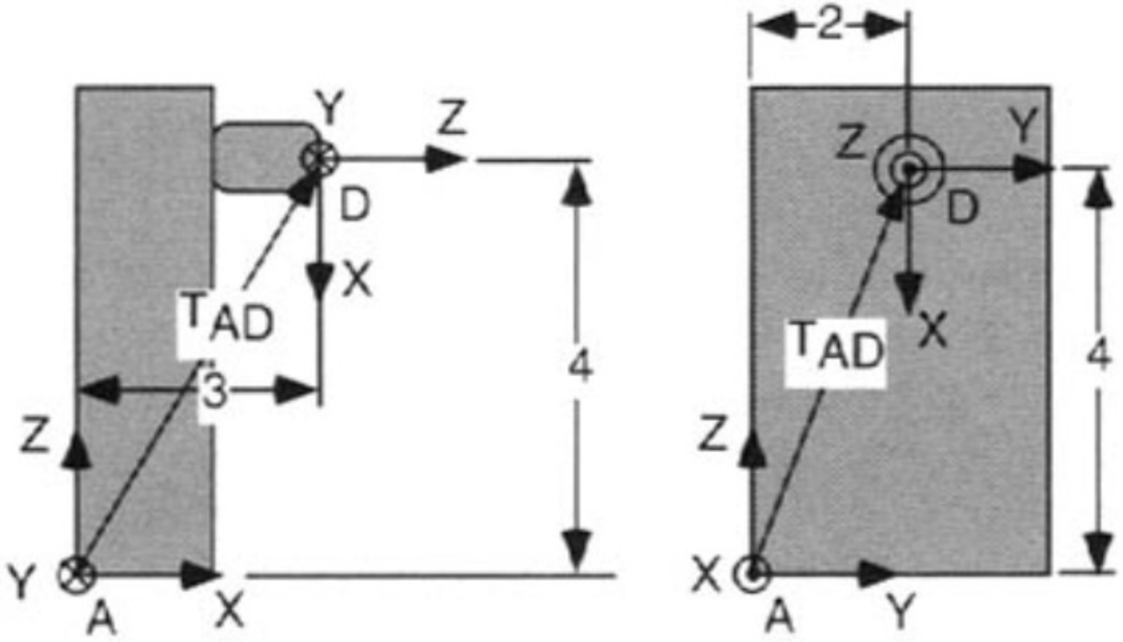


Sample : How to Build a Part and Place a Feature on It.

The transform equation may be read to say: "To go from part A's coordinate center at A to the tip of the peg feature at frame D, go 3 units along frame A's *X*-axis, 2 units along *Y,* and 4 units along Z, and then rotate 90° about frame A's relocated *Y*-axis."

$$>> T_{AD} = trans(3,2,4)roty(dtr(90))$$

$$T_{AD} = \begin{bmatrix} 0 & 0 & 1 & 3 \\ 0 & 1 & 0 & 2 \\ -1 & 0 & 0 & 4 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

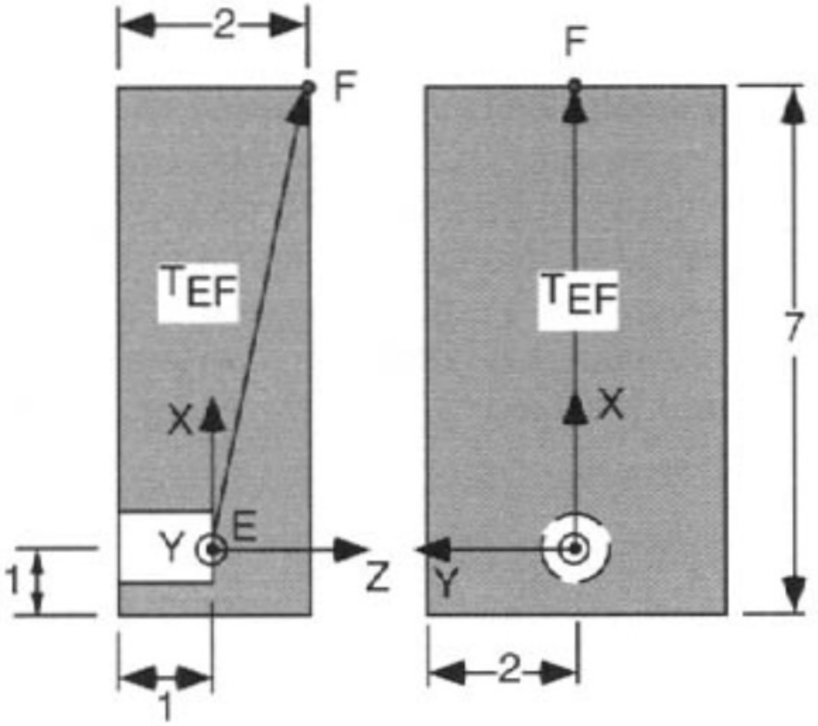


Sample : Construction of a Second Part

This part has a hole feature on it as well as a point F that is one end of a KC. The transform equation may be read to say: "To go from the bottom of the hole to point F, go 6 units along frame E's *X* axis and 1 unit along its Z axis."

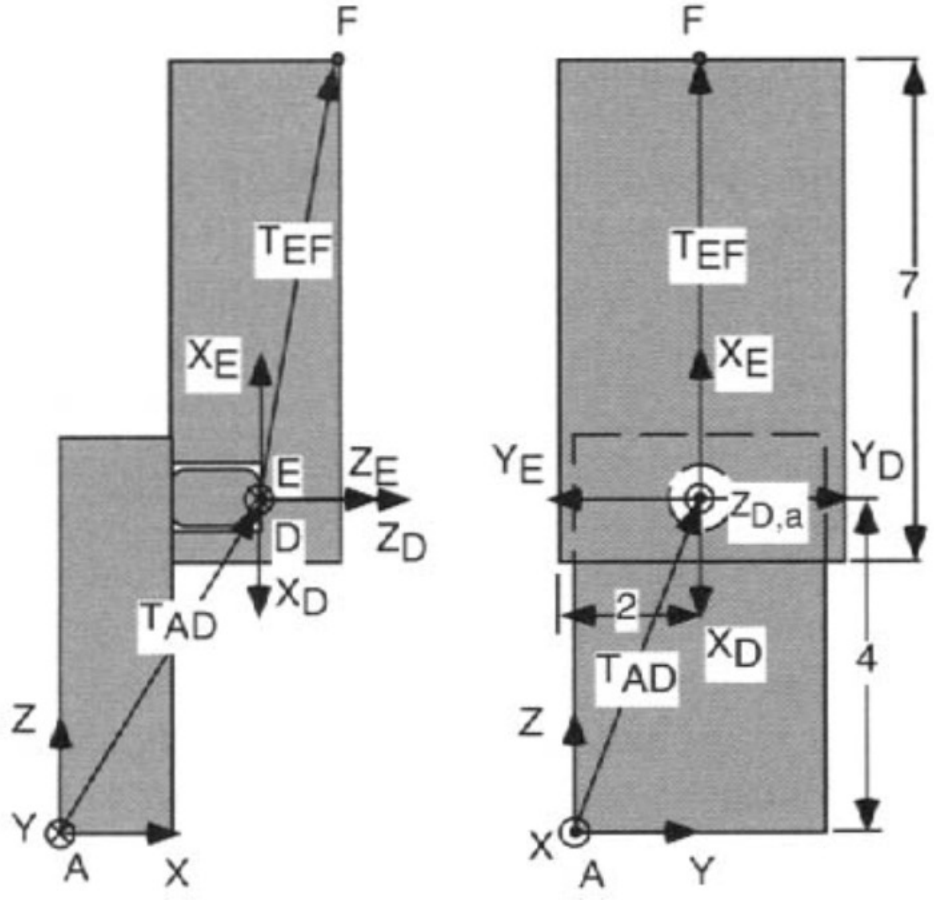
$$>> T_{EF} = trans\,(6,0,1)$$

$$T_{EF} = \begin{bmatrix} 1 & 0 & 0 & 6 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 1 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$



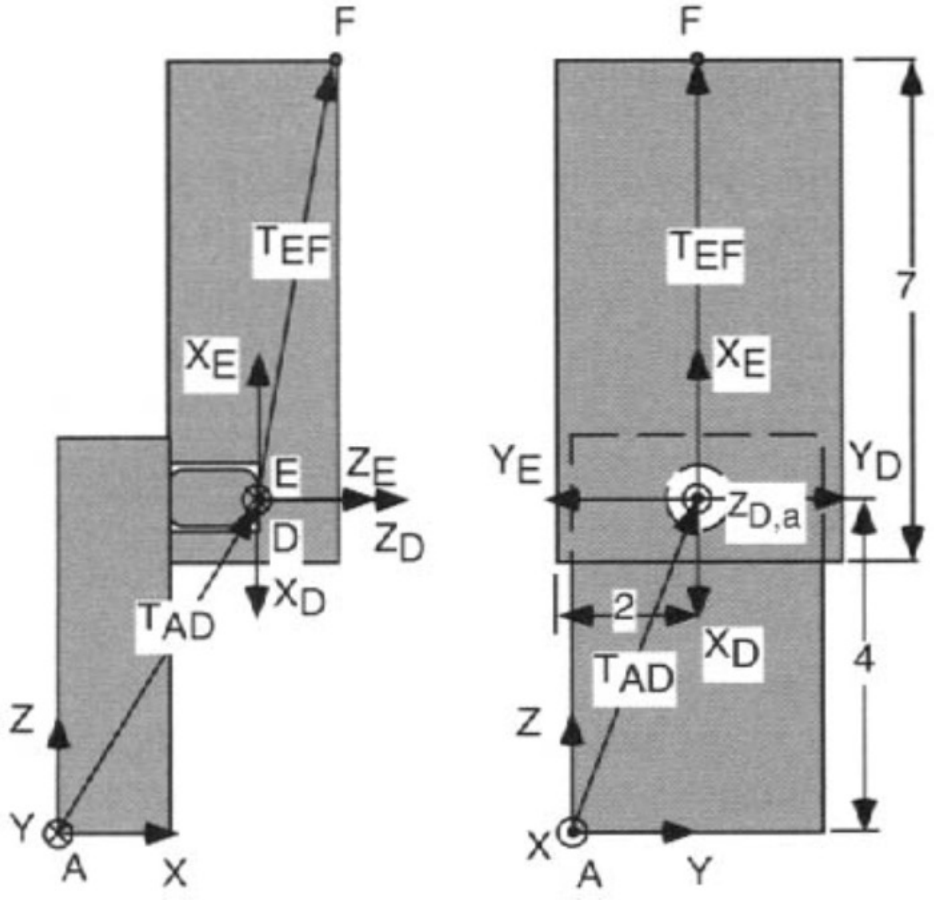
Sample : Assembling Two Parts

These two parts are "assembled" by placing frame D of the pin on the first part onto frame E of the hole on the second part.



Sample : Assembling Two Parts

An interface transform T_{DE} is needed because the axes of these frames are not aligned in the same way. The equation for assembly transform T_{AP} may be read to say: "To go from frame A to KC point F, follow transform T_{AD} *TAD,* then align frame D and frame E by rotating 180° about frame D's Z axis, then follow transform T_{EF}.



>> T_{DE} = rotz (dtr(180))

$$T_{DE} = \begin{bmatrix} -1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

>> $T_{AF} = T_{AD} T_{DE} T_{EF}$

$$T_{AF} = \begin{bmatrix} 0 & 0 & 1 & 4 \\ 0 & -1 & 0 & 2 \\ 1 & 0 & 0 & 10 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Assembly representations

Each individual part is represented by its geometric model, and the assembly is represented by the relative position and orientation of each individual part in the final assembled configuration. Most non-geometric information such as fits or joints is stored as text labels.

Representation Schemes :

- Graph Structure
- Location Graph
- Virtual Link

Assembly representations

Assembly data base stores:

- The geometric models of individual parts.
- The spatial positions and orientations of the parts in the assembly.
- Attachment relationships between parts.
- The inherent problem.

Graph Structure

An assembly graph is used to represent the **final assembly** of a genome (or metagenomes). In simple terms, the assembler builds this assembly graph based on reads and their overlap information.

An assembly model is represented by a graph structure.

Graph Structure

Each node represents an individual parts / subassembly.

Arc (branch) represents relationship among parts.

Four kinds of relationship exist:

P : ‘part-of’ relationship

Logical containment of one object in another.

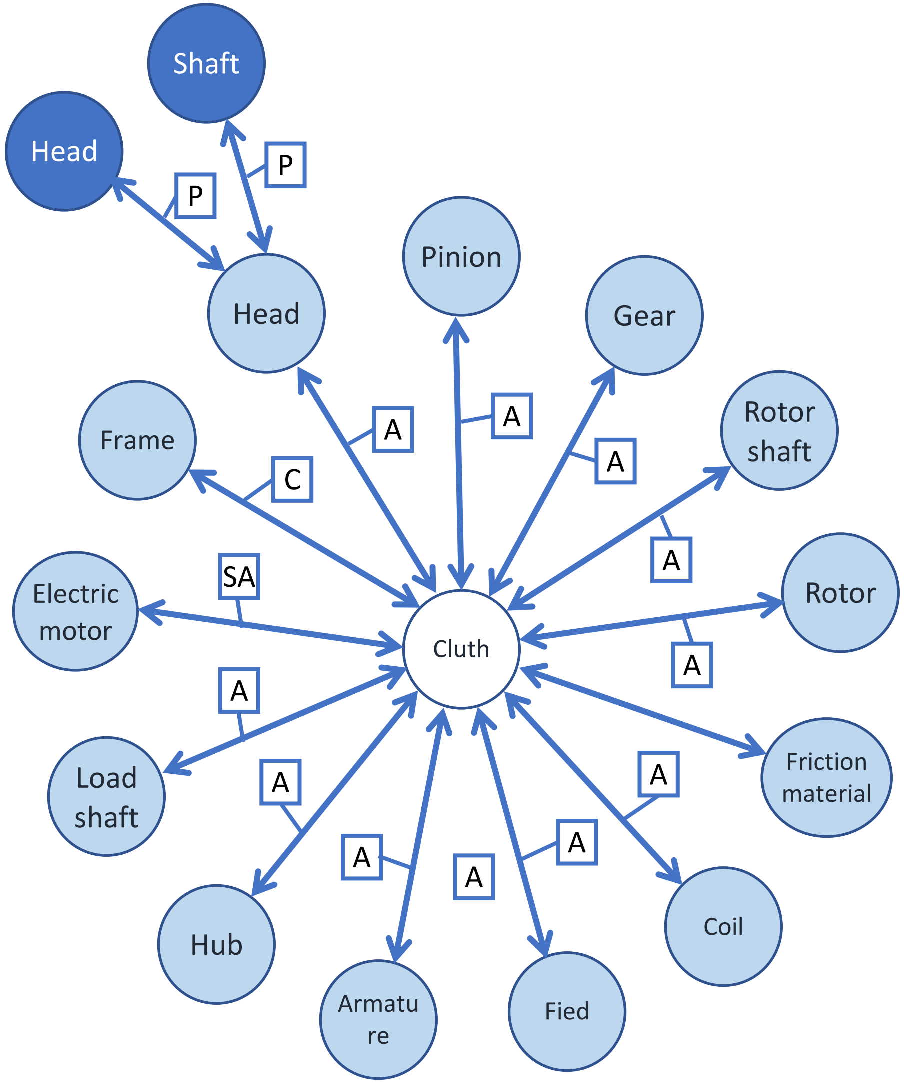
A : ‘attachment’ relationship

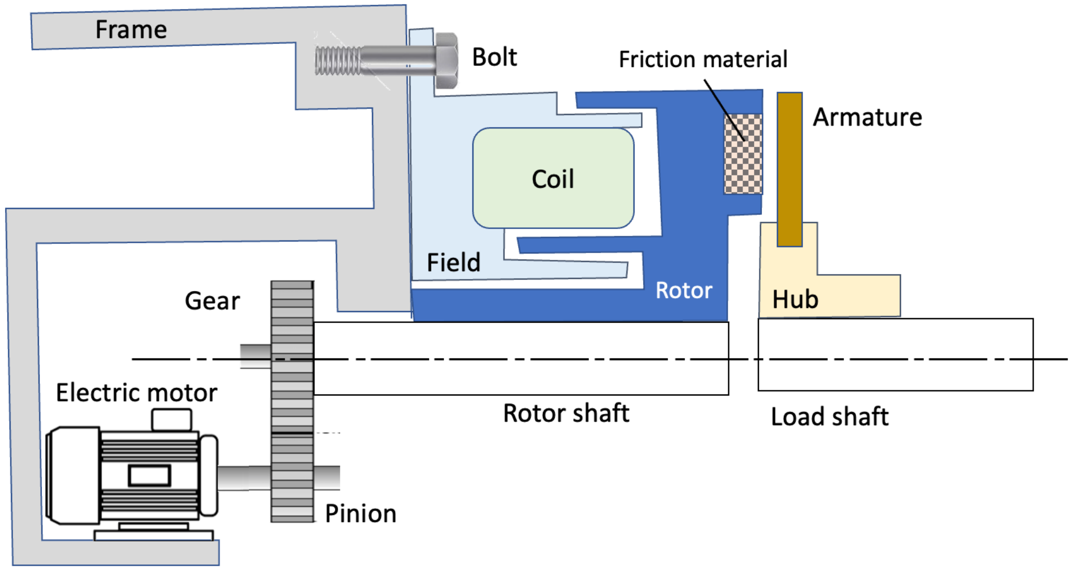
C : ‘constraint’ relationship

physical constraints

SA : ‘sub-assembly’ relationship

Example : electric clutch





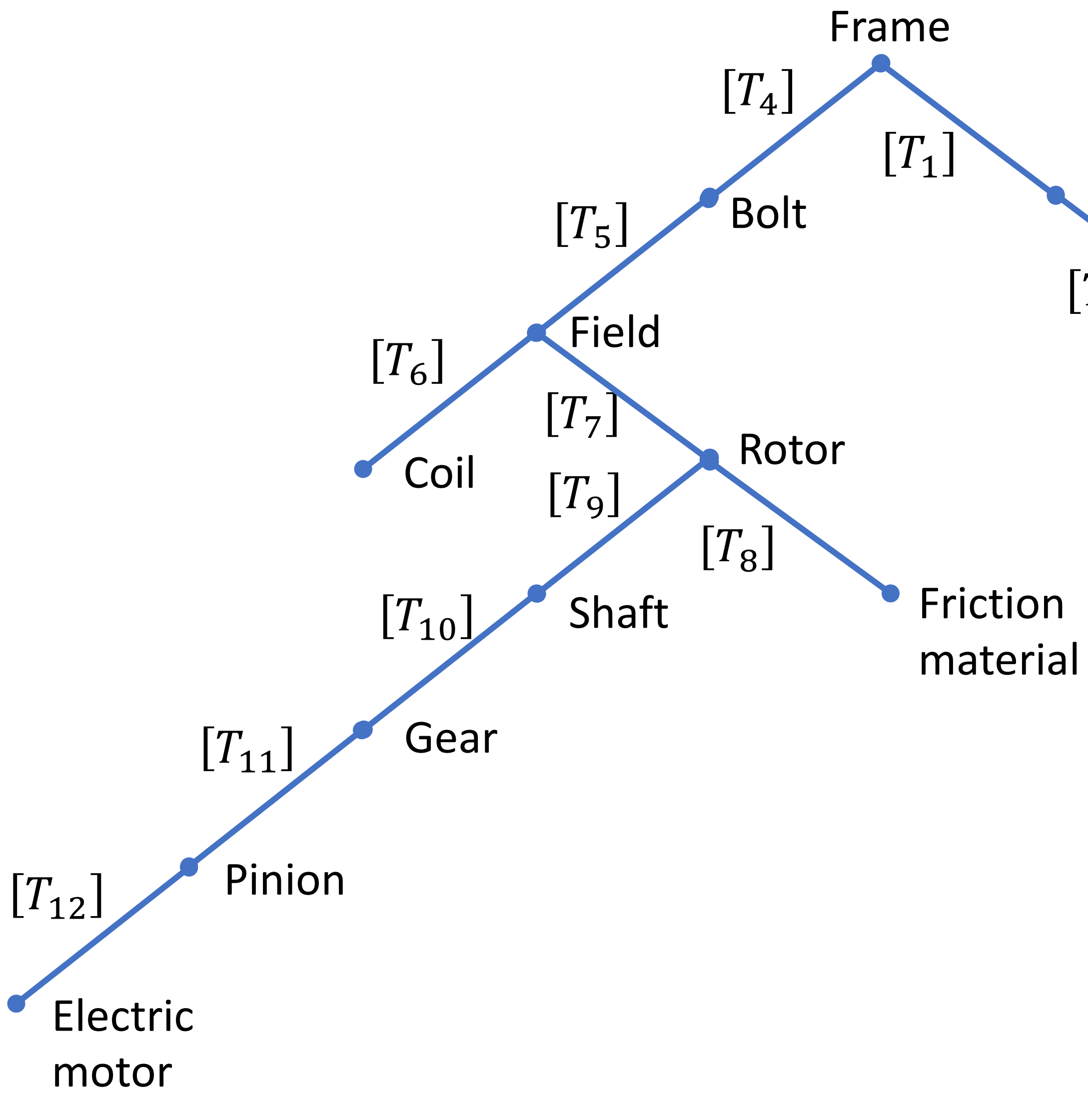
Location Graph

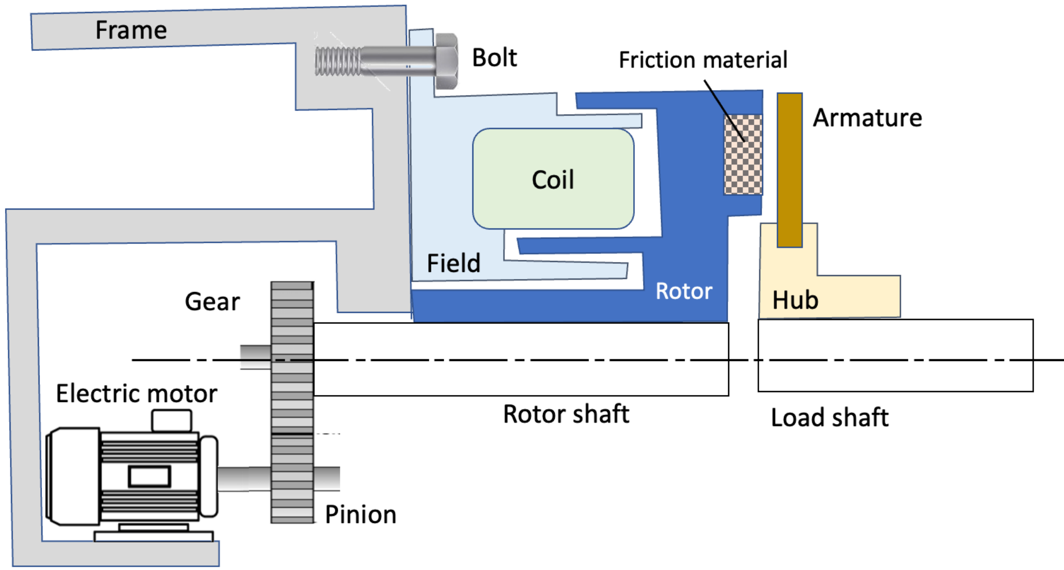
Coordinate system is the means used to specify location of one part relative to other.

A chain of locations can be defined such that each location is defined in terms of [T] another part's coordinate system.

A set of these chains results in a location graph. Part to part is related by the transformation matrix [T].

Example : electric clutch





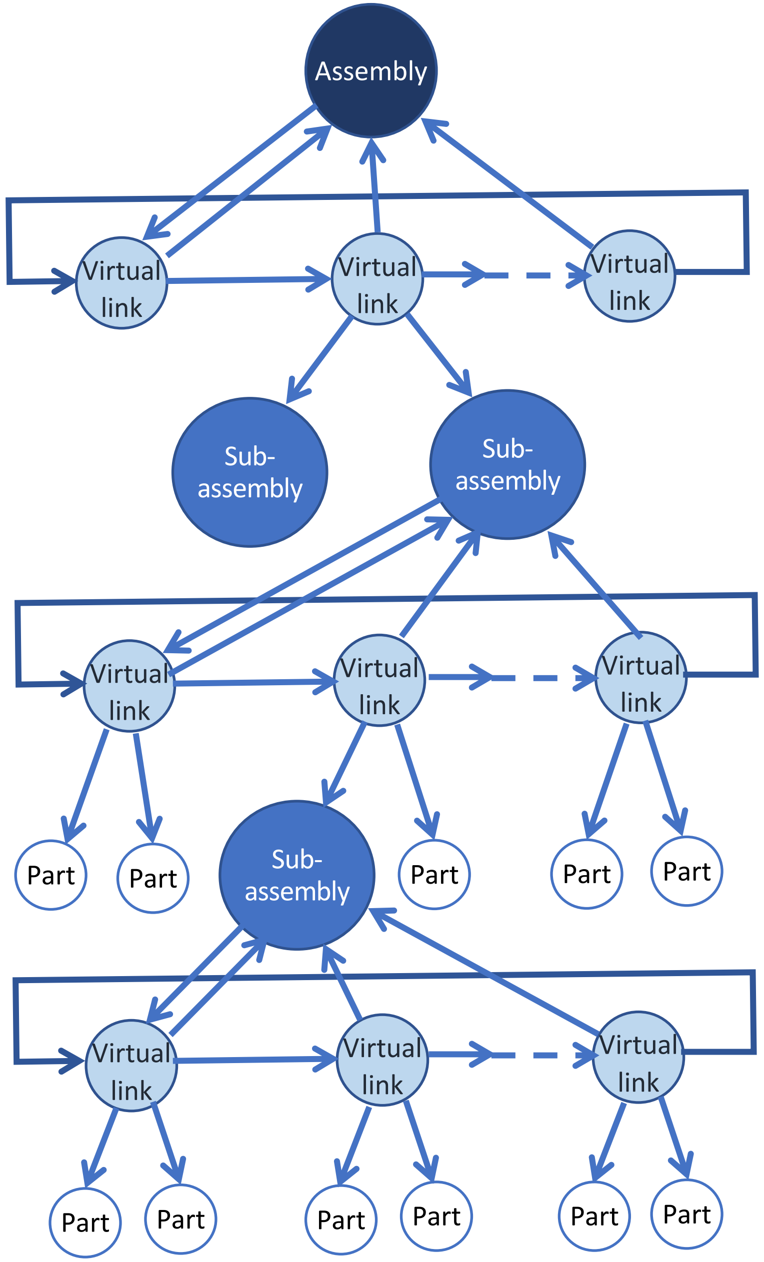
Virtual Link

Graph structure and location graph requires the user to input transformation matrix. Virtual link requires more basic information (mating conditions) used to calculate the transformation matrices.

Virtual link is defined as the complete set of information required to describe the type of attachment and the mating conditions between the mating pair. Data structure of this scheme is based on the concept of virtual link.

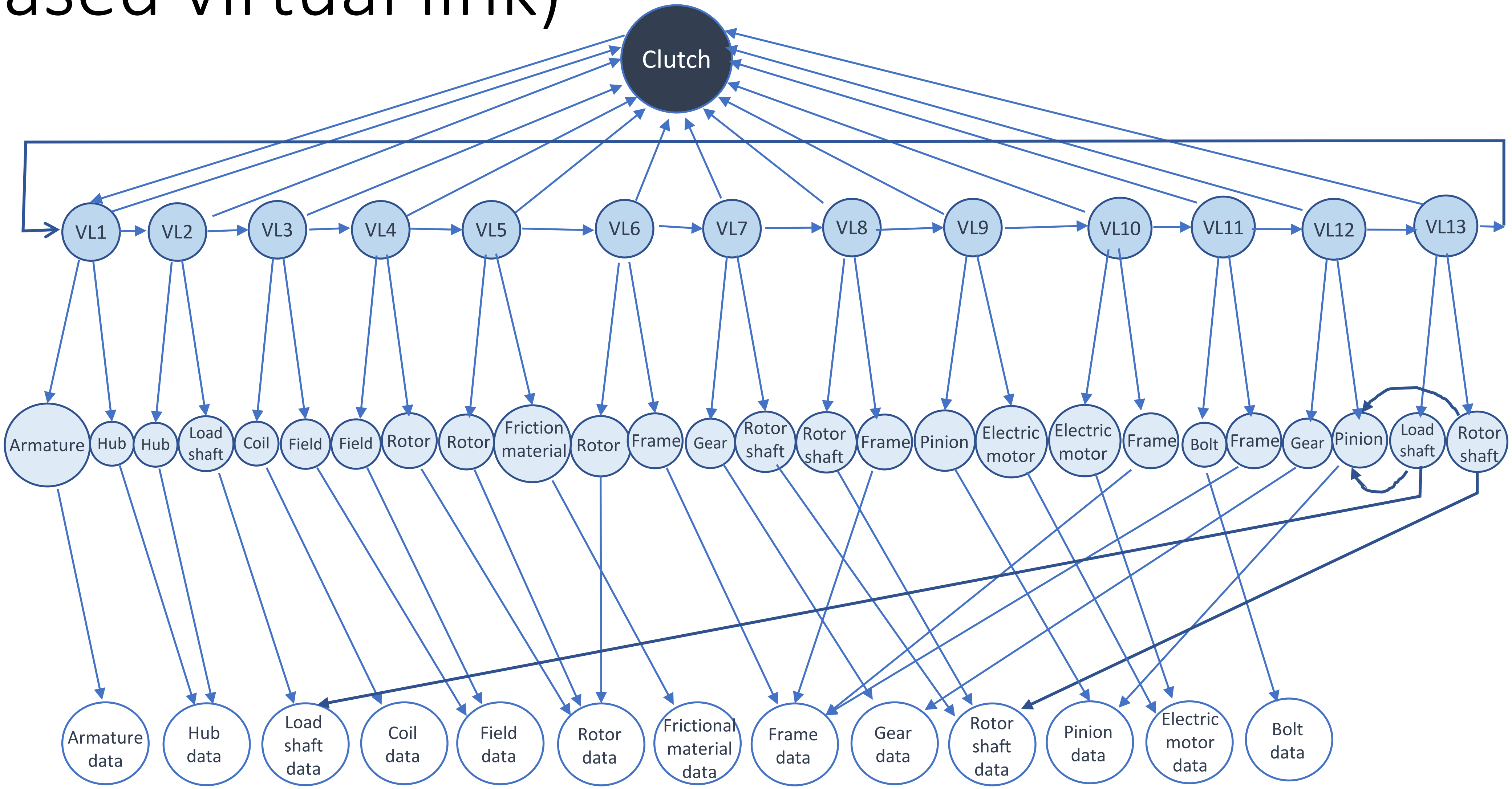
Virtual Link

Virtual link defined as the complete set of information required to describe the type of attachment and the mating conditions between the the mating pair.

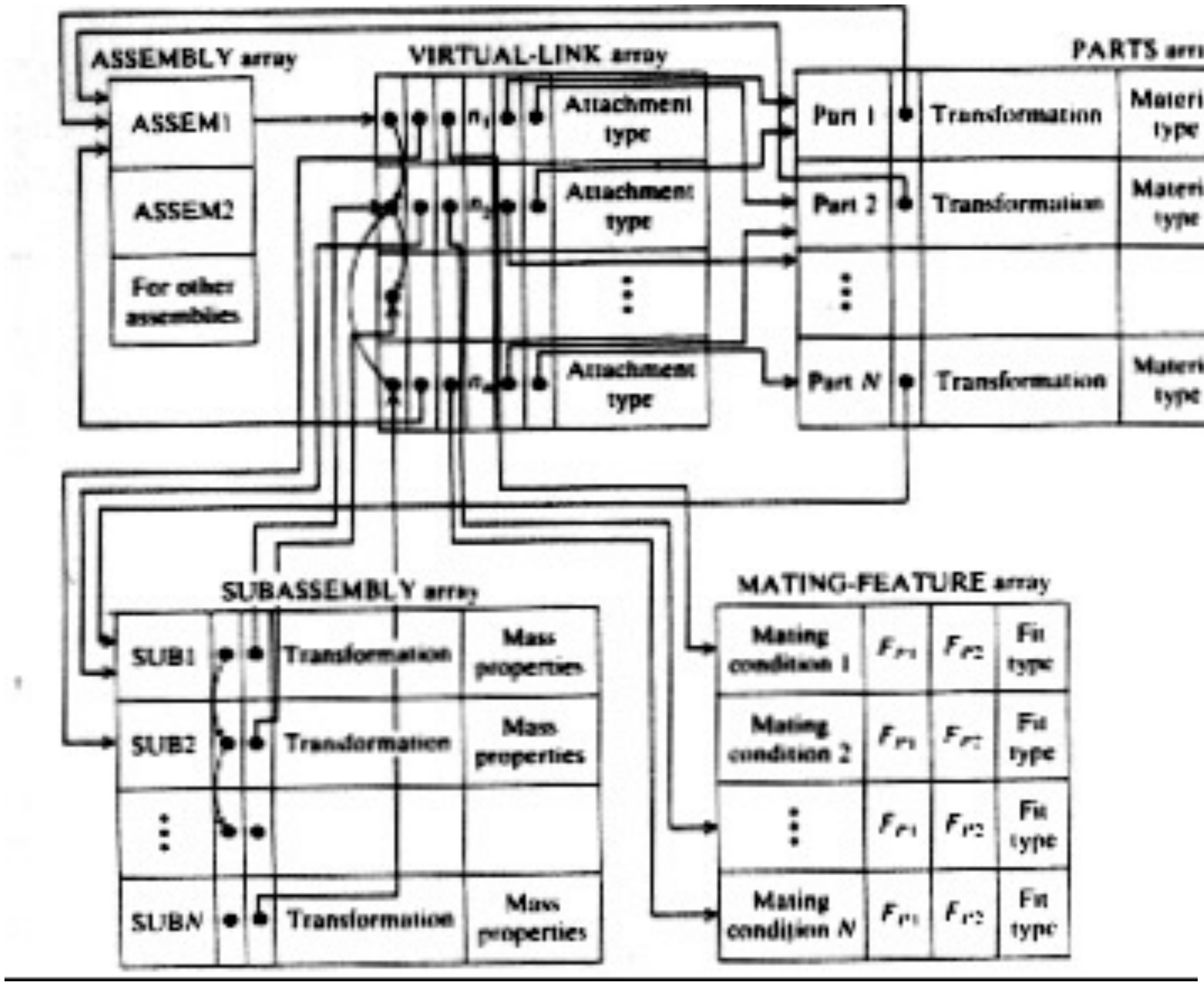


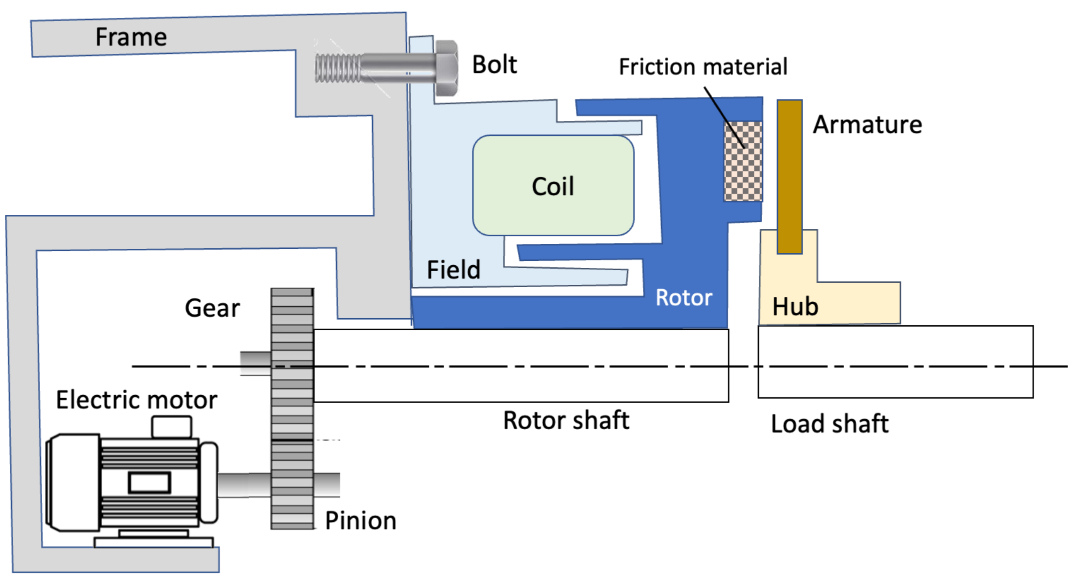
Assembly graph structure based on virtual link

Example : electric clutch (graph structure based virtual link)

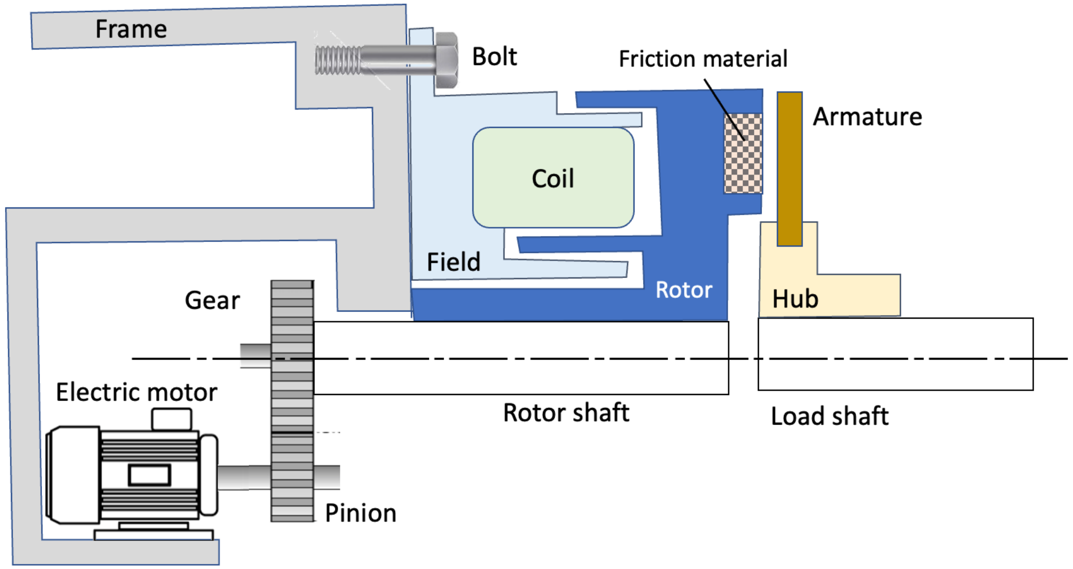


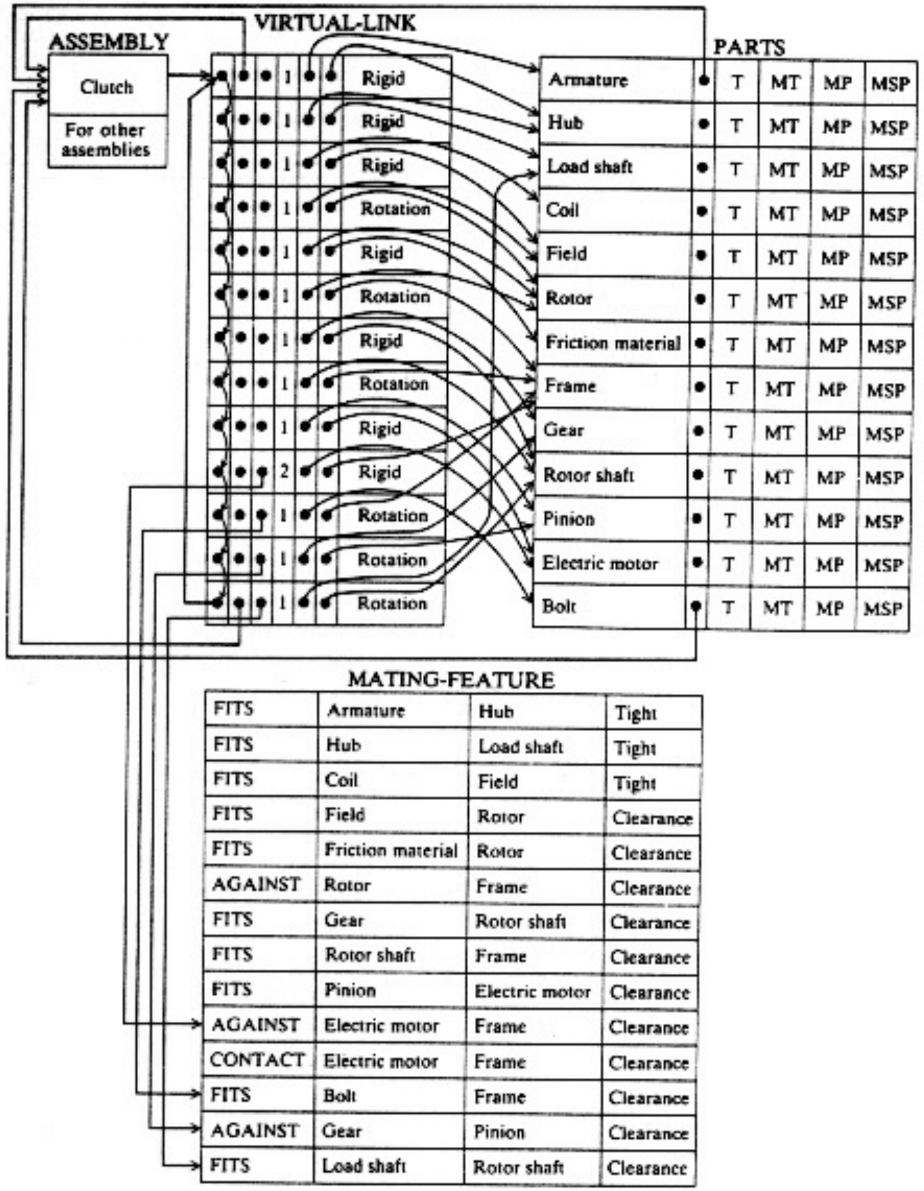
Example : electric clutch (Assembly based on virtual link)





Example : electric clutch (Assembly based on virtual link)





Assembling sequence

It is always useful when studying the assembly of a part. In most assembly, there are multiple assembly sequence:

Not unique In most assembly, there are more than one assembly sequence to generate assemblies from their respective parts.

Production engineer must decide on most optimum sequence.

Generation of Assembling Sequences

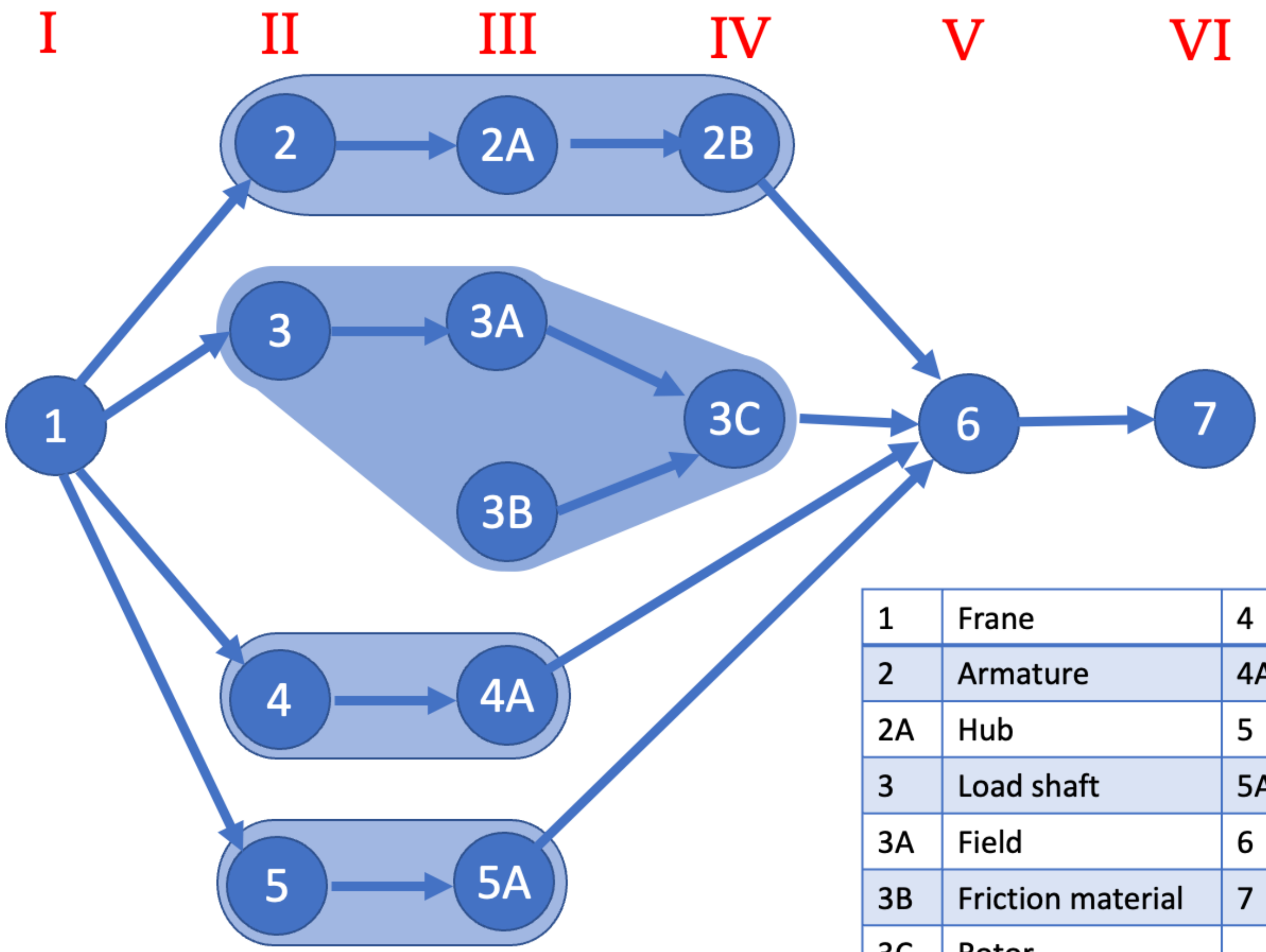
- Precedence Diagram
- Liaison - Sequence Analysis
- Precedence Graph

Precedence Diagram

Designed to show all the possible assembly sequences of a product. Each individual assembly operation is assigned a number.

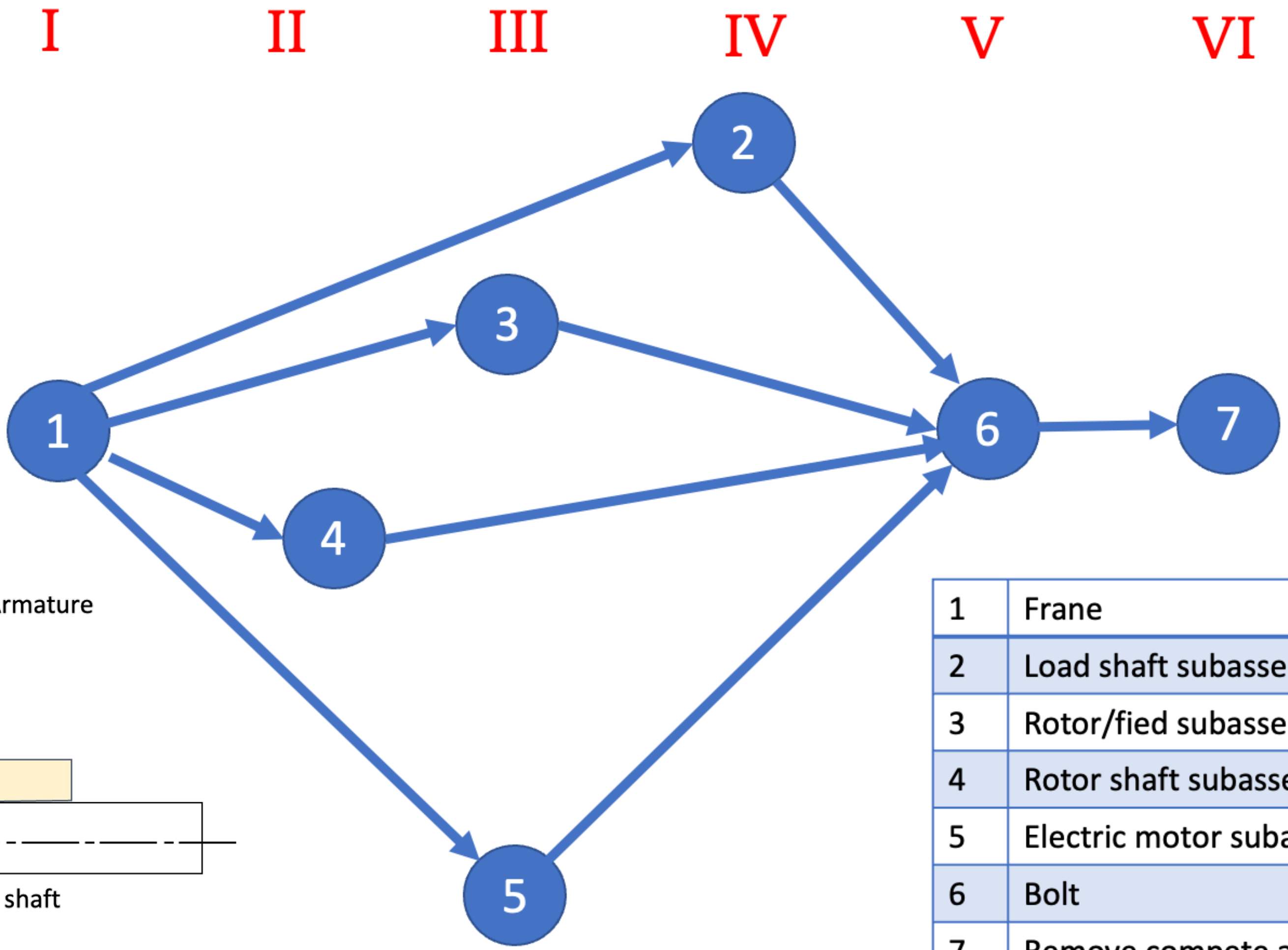
It show all the possible assembly sequences of a product. To develop the precedence diagram for a product, each individual assembly operation is assigned a number & is represented by circle with number inscribed. Circles are connected by arrows showing the precedence relations.

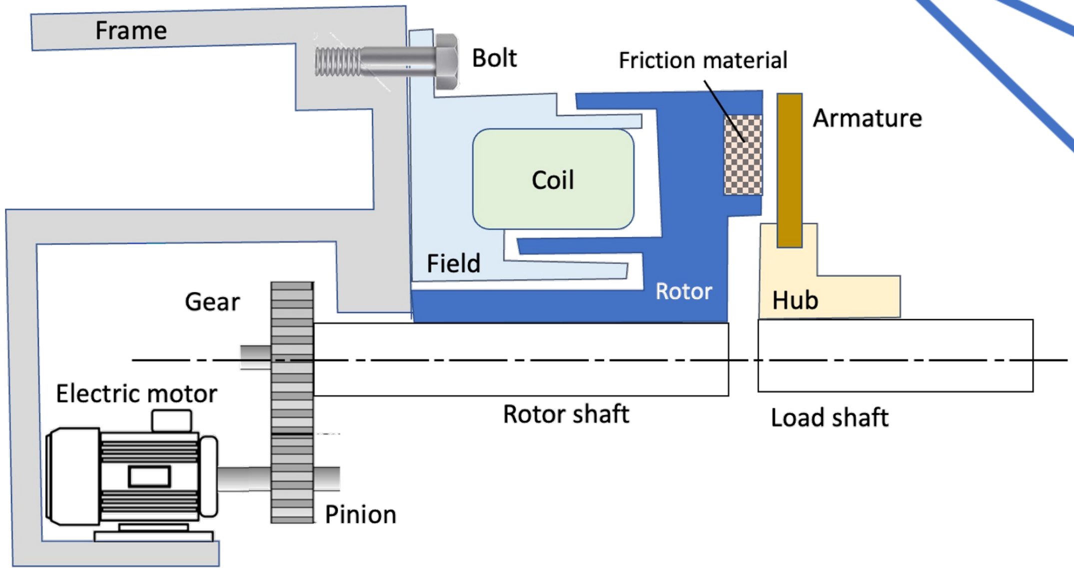
Example : electric clutch (assembly based on individual parts)



1	Frane	4	Gear
2	Armature	4A	Rotor shaft
2A	Hub	5	Pinion
3	Load shaft	5A	Electric motor
3A	Field	6	Bolt
3B	Friction material	7	Remove compete assembly
3C	Rotor		

Example : electric clutch (assembly based on subassemblies)

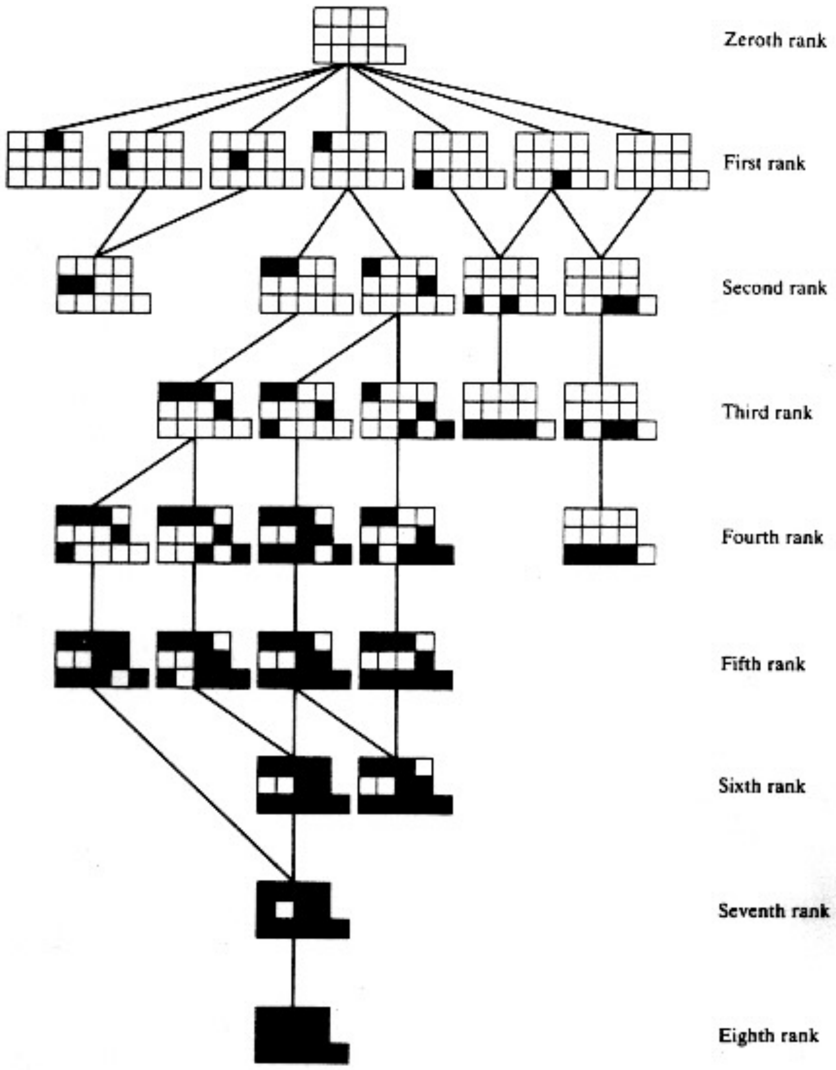




1	Frane
2	Load shaft subassembly
3	Rotor/fied subassembly
4	Rotor shaft subassembly
5	Electric motor subassembly
6	Bolt
7	Remove compete assembly

Liaison - Sequence Analysis

Liaison - sequence analysis use precedence relations;
In precedence diagram: engineer generates possible sequence directly.
In liaison method: asks a series of questions to engineers about mating condition and precedence relationships.
Generate sequences: manually or algorithmically.



Liaison diagram

A liaison diagram is a simple graph that uses nodes to represent parts and lines between nodes to represent liaisons or connections between parts.

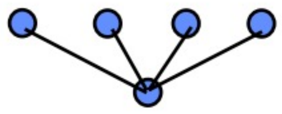
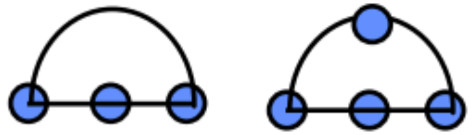
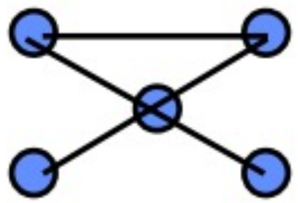
A simple graph that denotes parts as nodes and connections as arcs.

Can be augmented with information about the connection.

- **Node:** represent parts
- **Line:** represent any mating conditions between parts.

Each part has no more than one liaison(line) with any other part.

Assembly Types

Hub and spokes	Loop	Network	Stack
			

Key characteristics

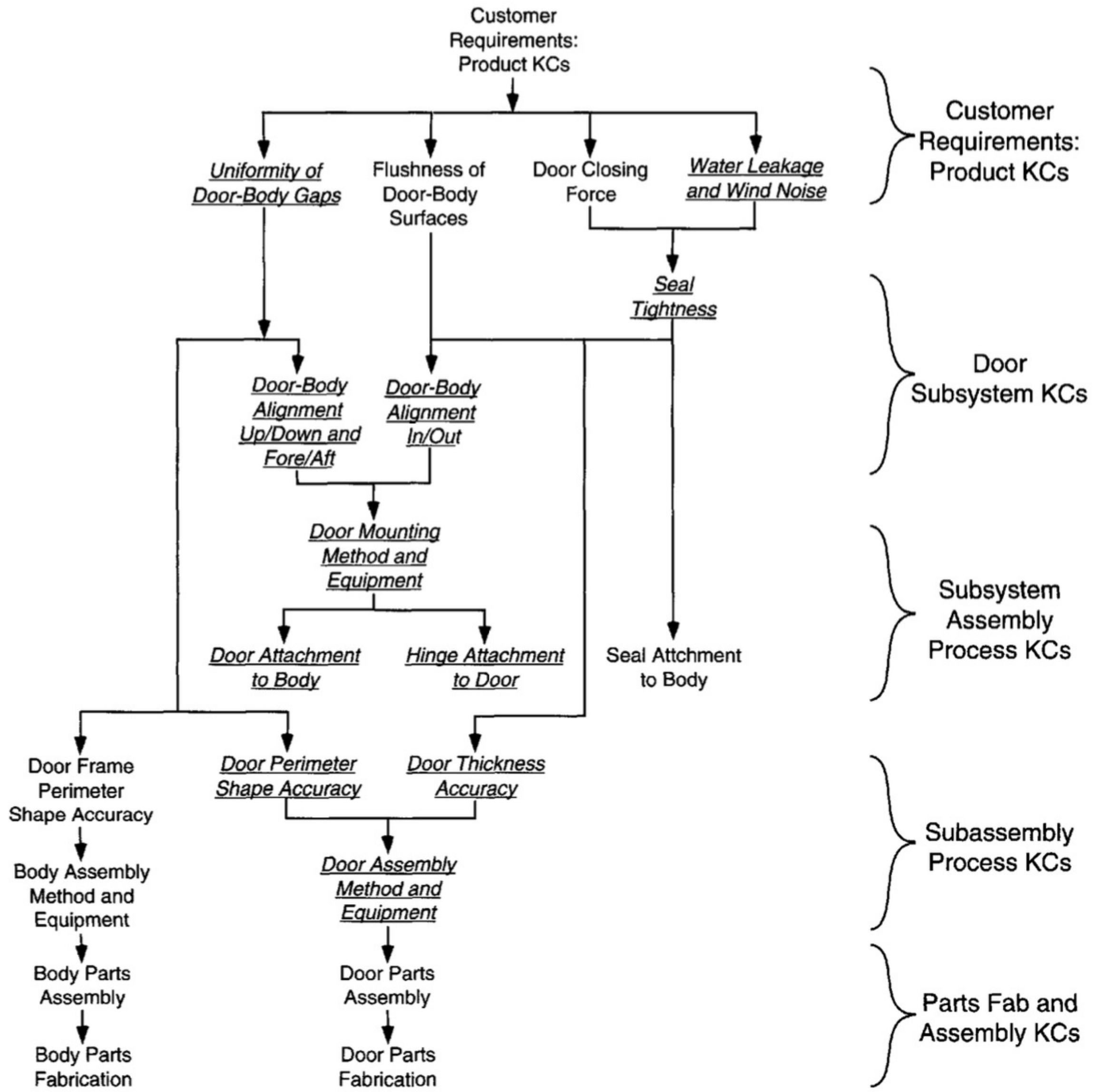
Key characteristics are the product, subassembly, part, and process features whose variation from nominal significantly impacts the final cost, performance [including the customer's perception of quality], or safety of a product. Special control should be applied to those KCs if the cost of variation justifies the cost of control.

Thornton, A. C., "A Mathematical Framework for the Key Characteristic Process," Research in Engineering Design, vol. 11, pp. 145-157, 1999.

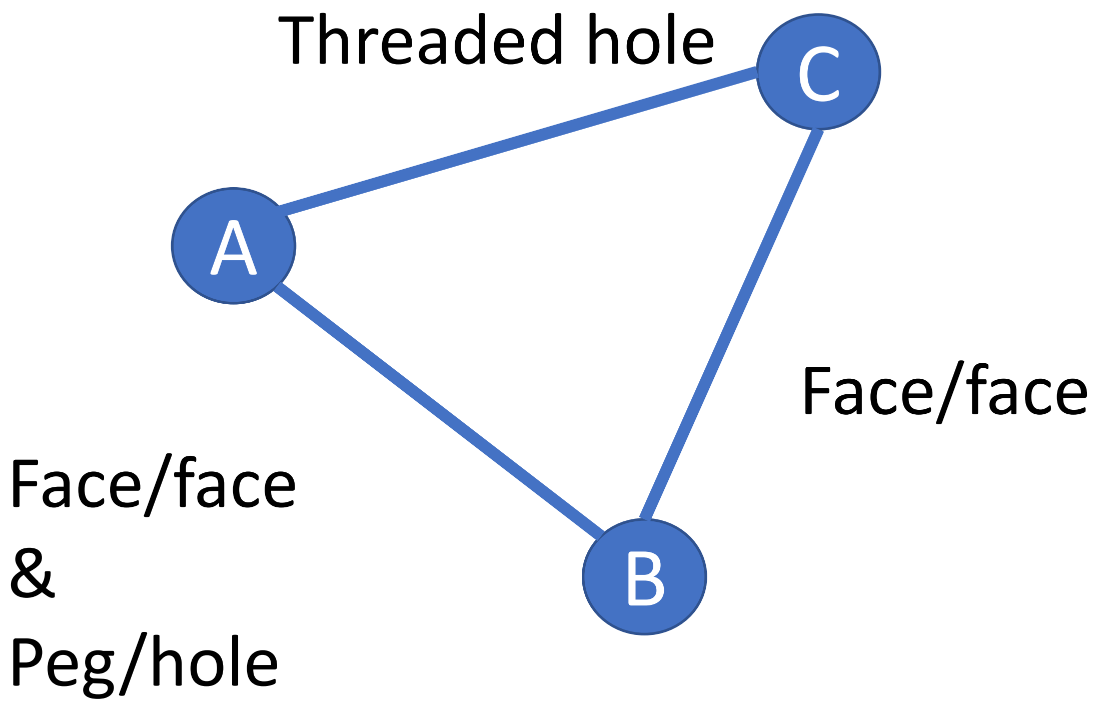
Key Characteristics Flowdown

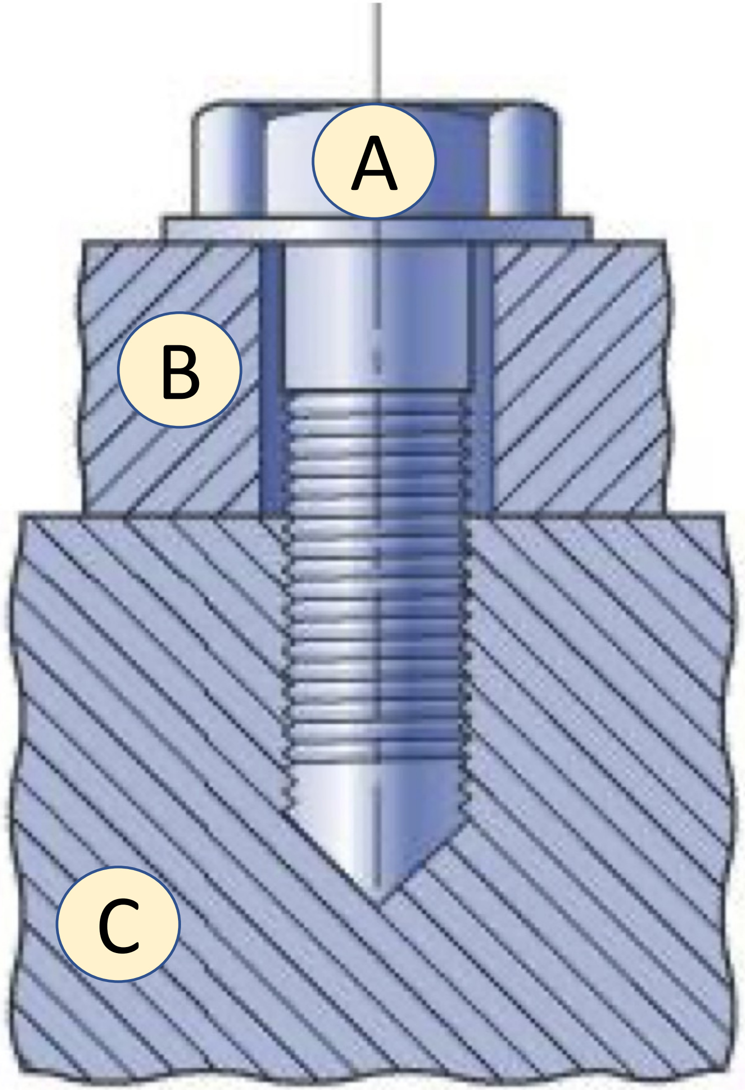
The example here is drawn from the auto industry and shows how KCs describing the customer's perception of a door can be flowed down through subassemblies, to features on parts, and finally to manufacturing processes.

Thornton, A. C., "A Mathematical Framework for the Key Characteristic Process," Research in Engineering Design, vol. 11, pp. 145-157, 1999.

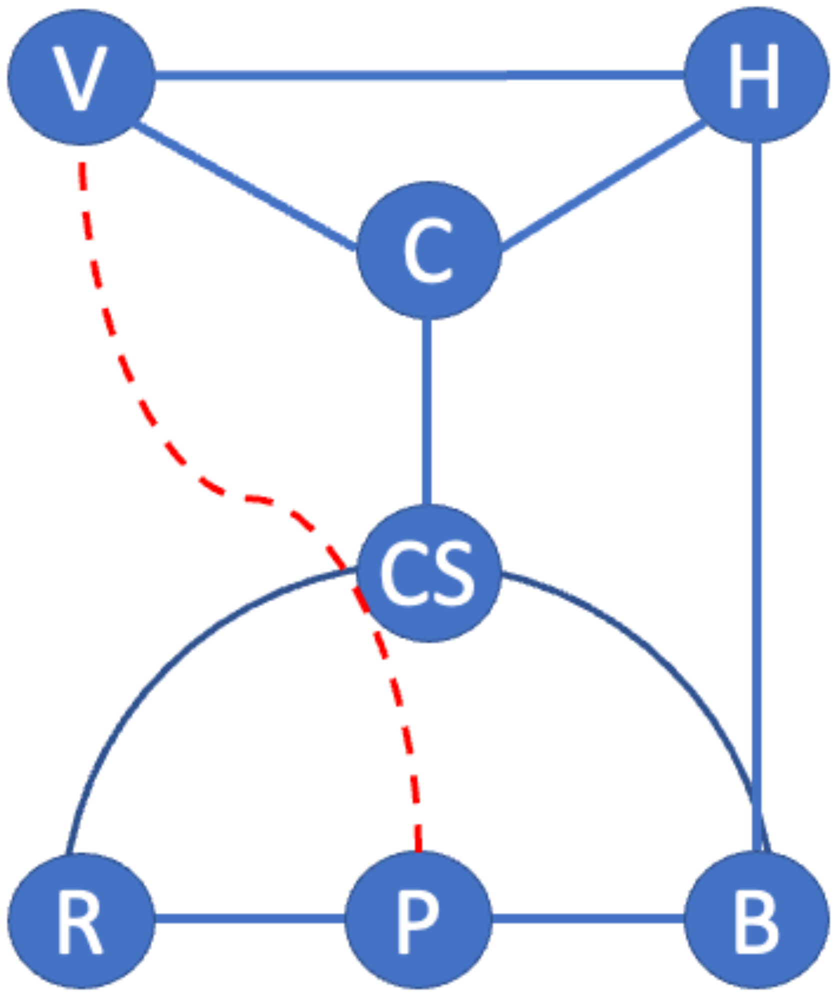


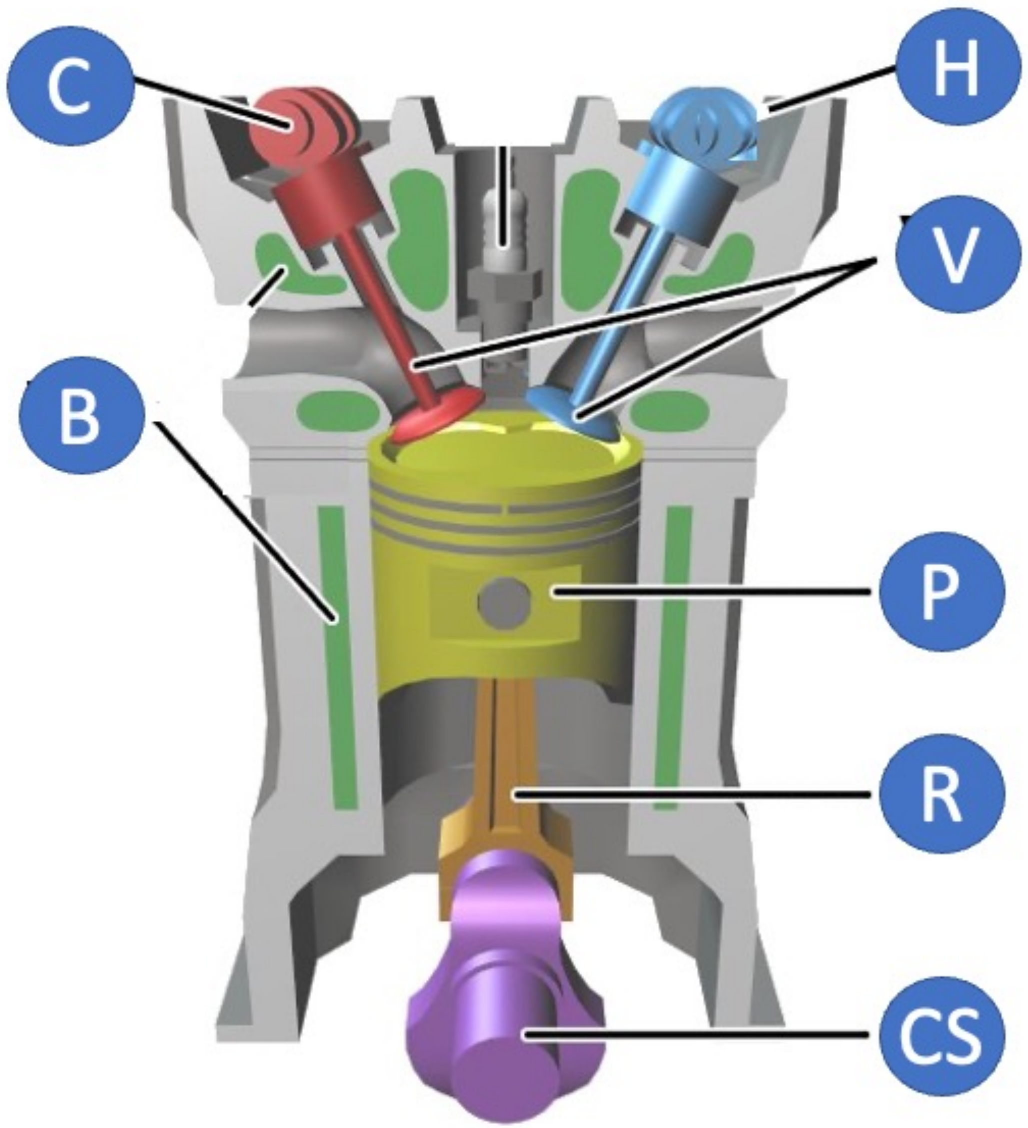
Liaison diagram : bolt connection



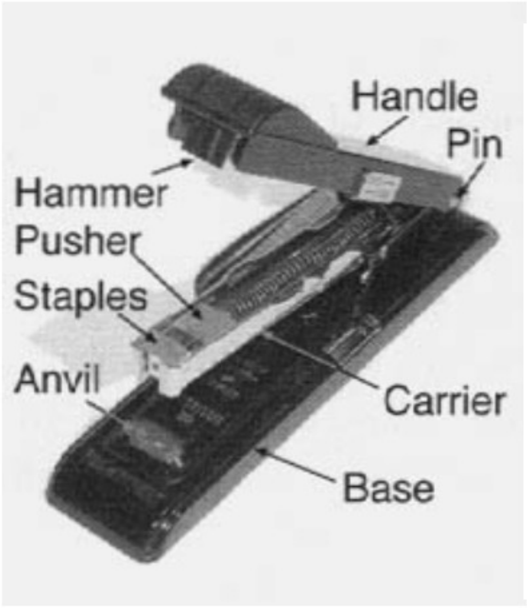


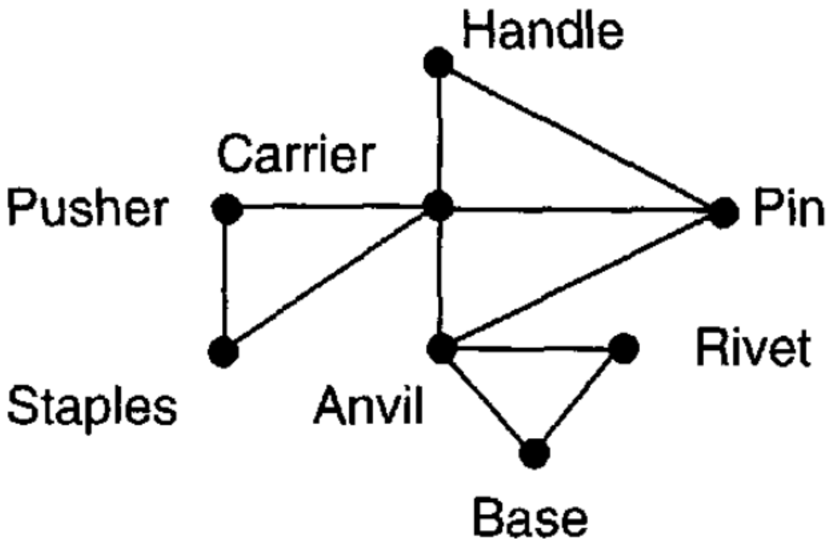
Liaison diagram

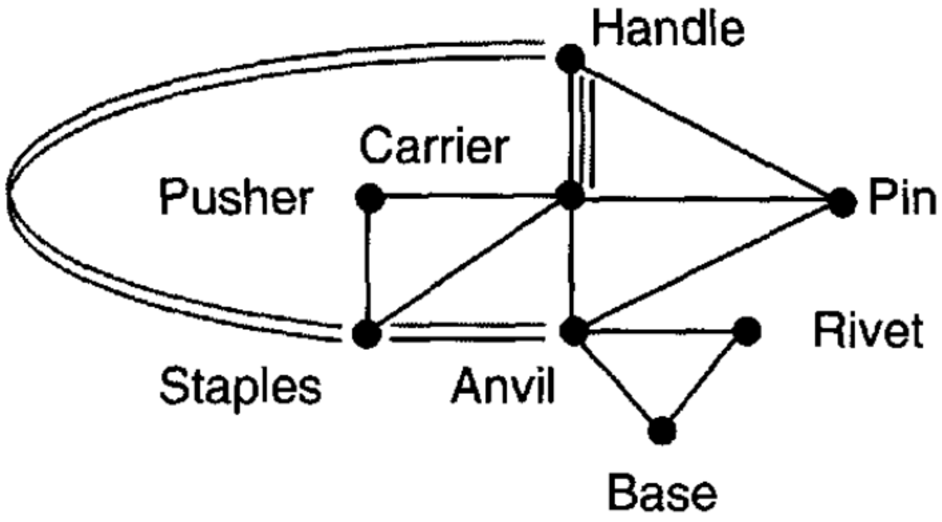




Liaison diagram : Desktop stapler

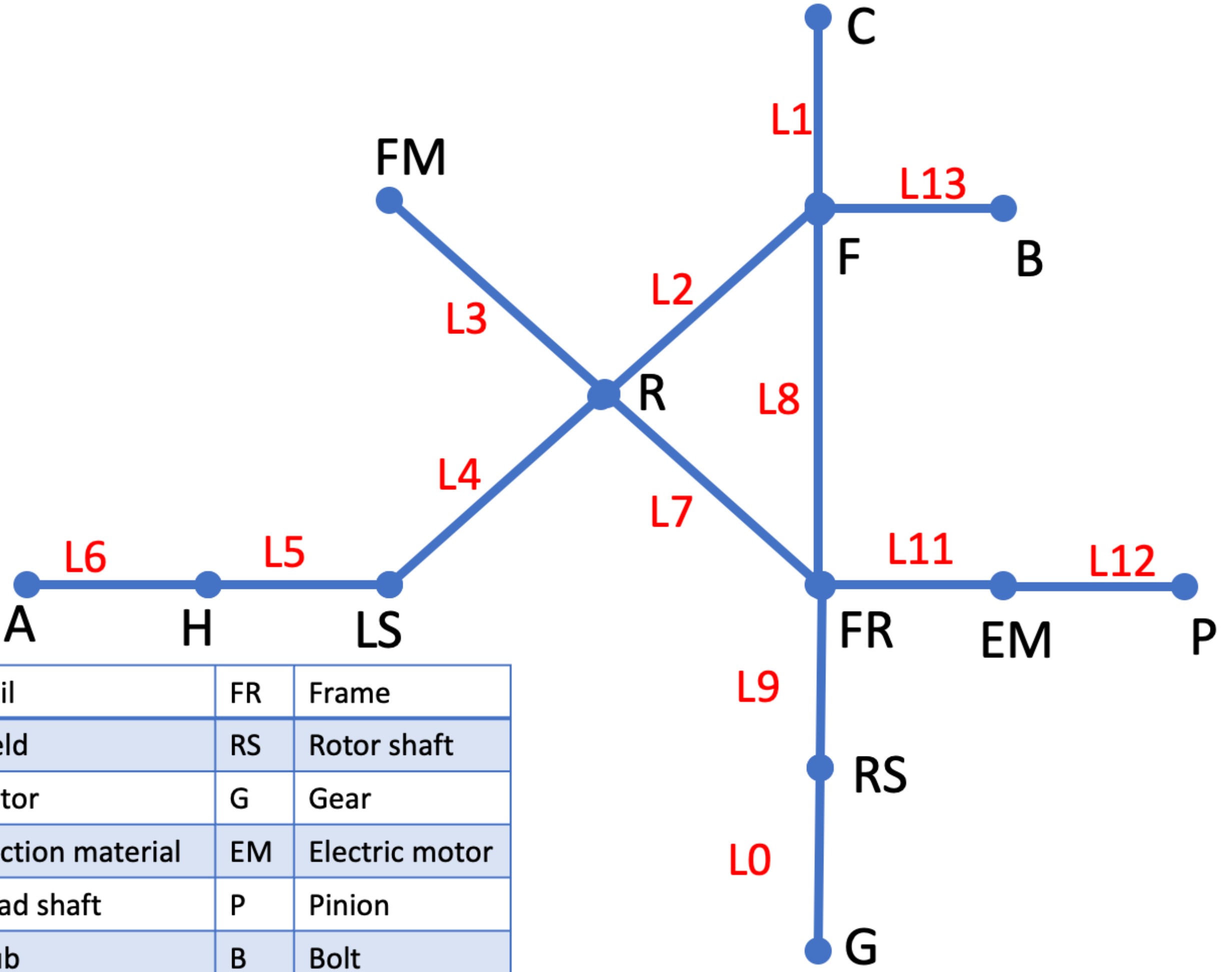




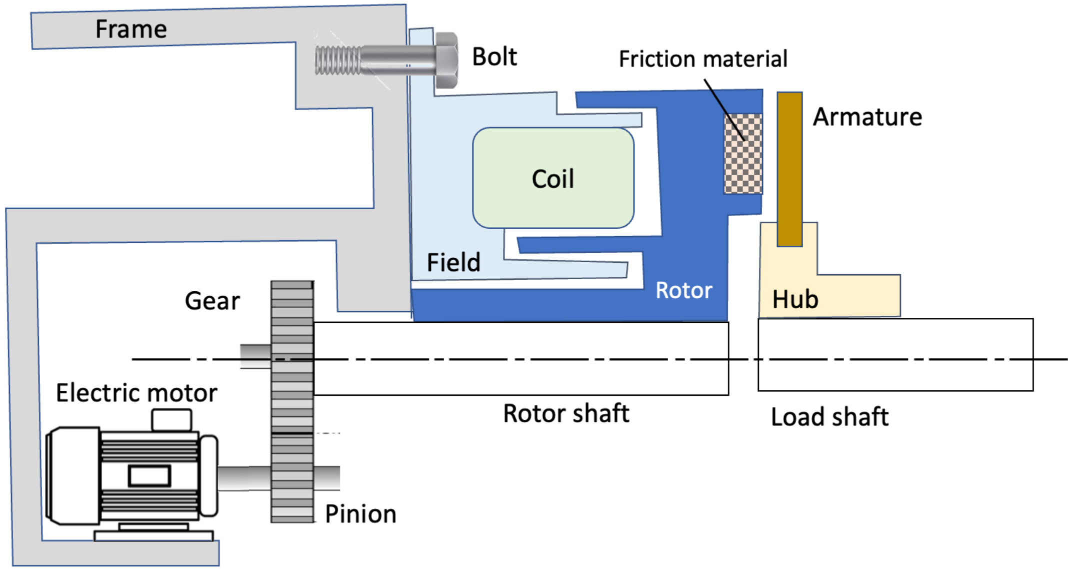


Liaison Diagram with Key Characteristics Indicated by Double Lines.

Example : electric clutch (Liaison diagram)



C	Coil	FR	Frame
F	Field	RS	Rotor shaft
R	Rotor	G	Gear
FM	Friction material	EM	Electric motor
LS	Load shaft	P	Pinion
H	Hub	B	Bolt
A	Armature		



Precedence Graph

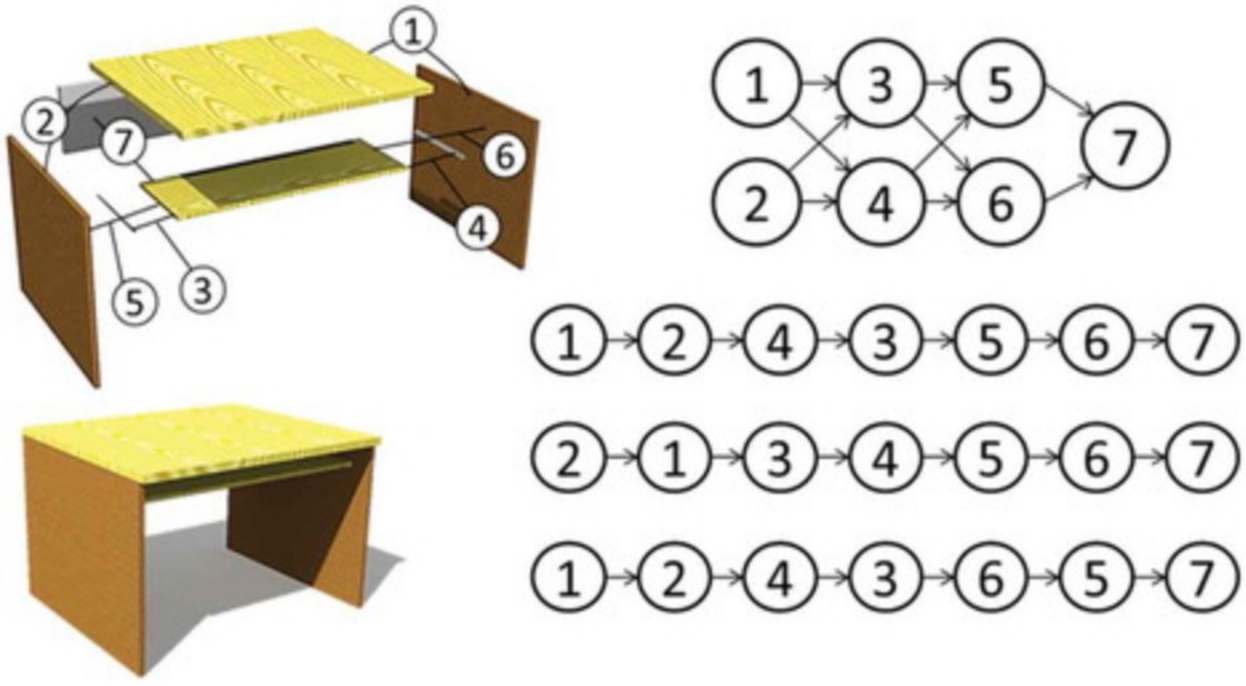
The representation mostly used in assembly planning is the precedence diagram or precedence graph, which contains all the valid sequences of an assembly. Even for the precedence diagrams, different representations have been proposed in the literature that include process times, levels of assembly, etc. .

Assembly sequence is generated with the aid of interference checking.

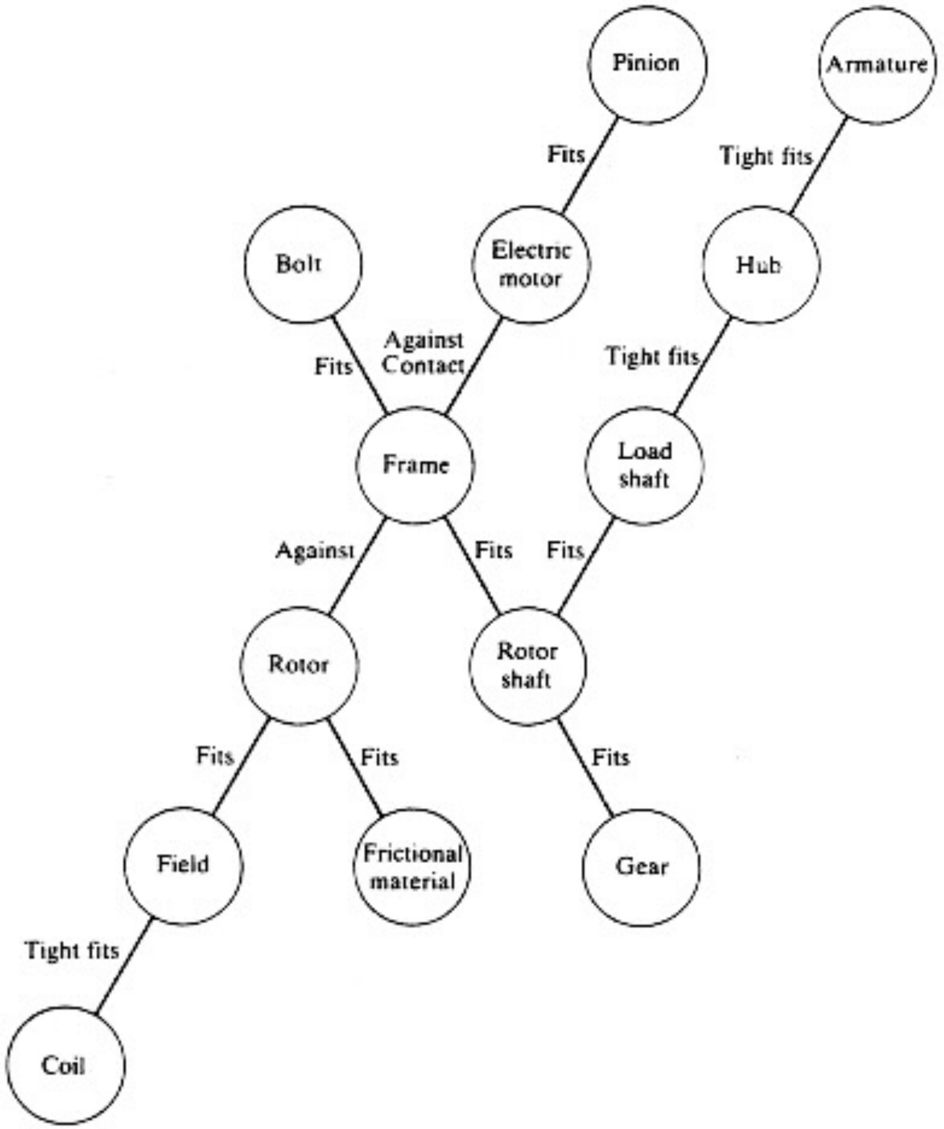
1. Input mating conditions.
2. Generate mating graph.

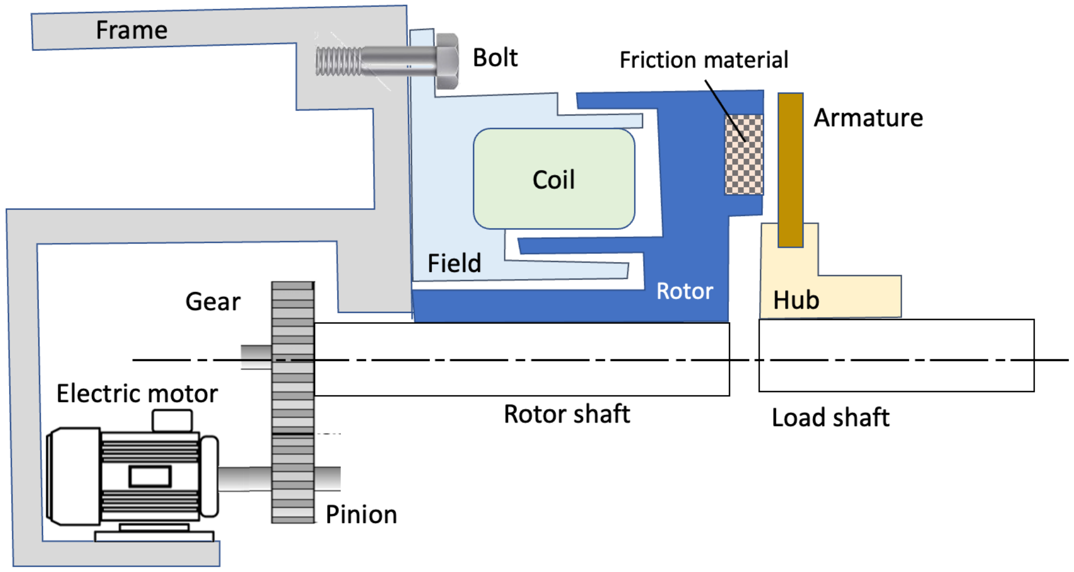
Precedence Graph

The diagram of a precedence graph, theoretically, presents all the possible assembly sequences of tasks for assembling a product. Identify the part that is connected to the largest, of parts by virtual links, the base part.

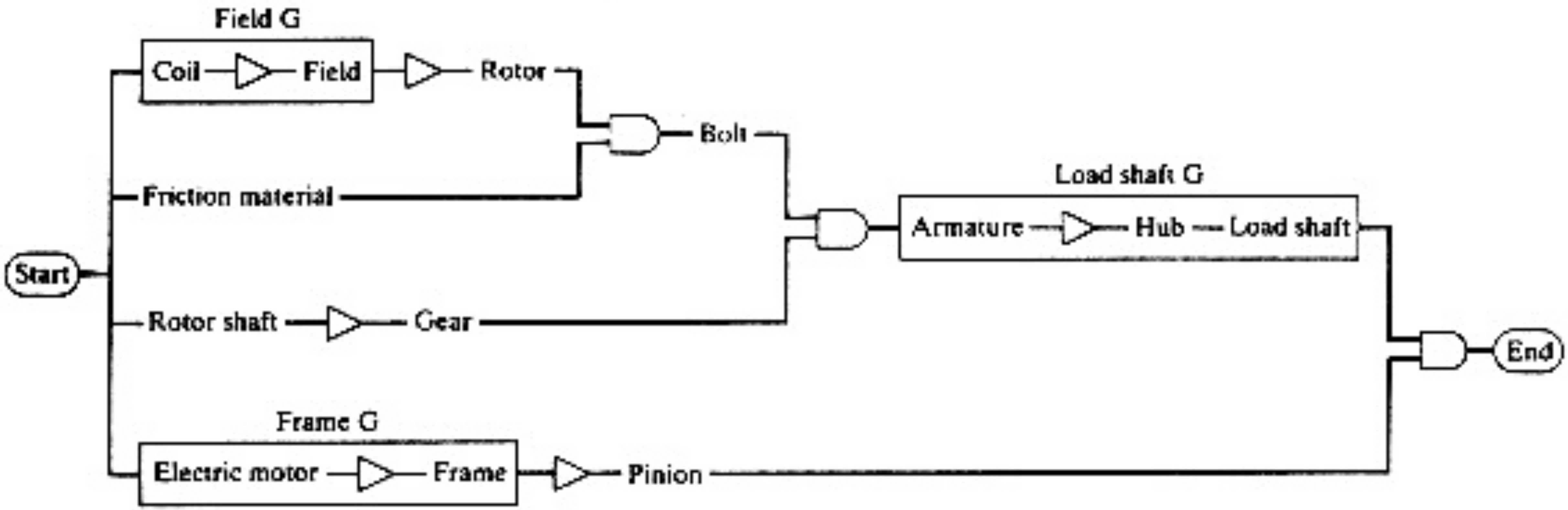


Example : electric clutch (mating graph)





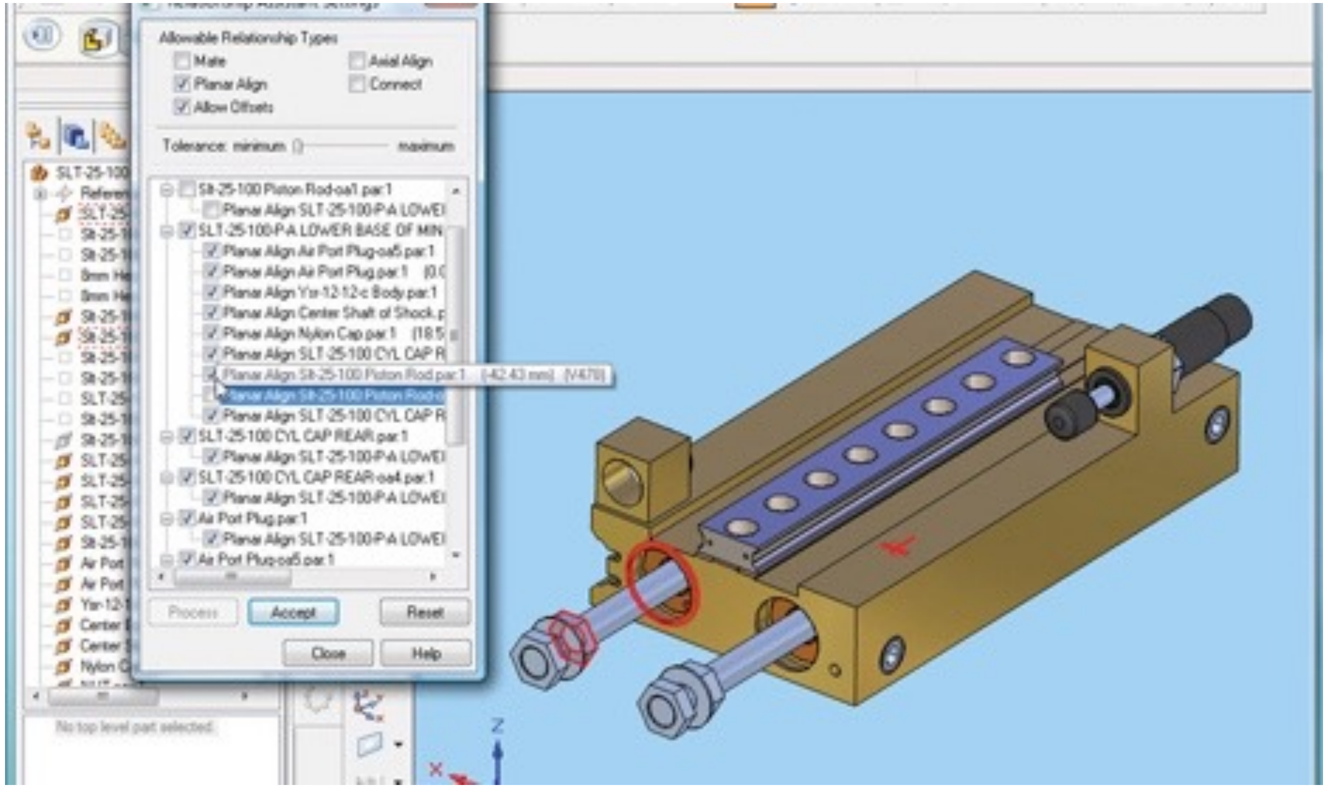
Example : electric clutch (Precedence Graph)



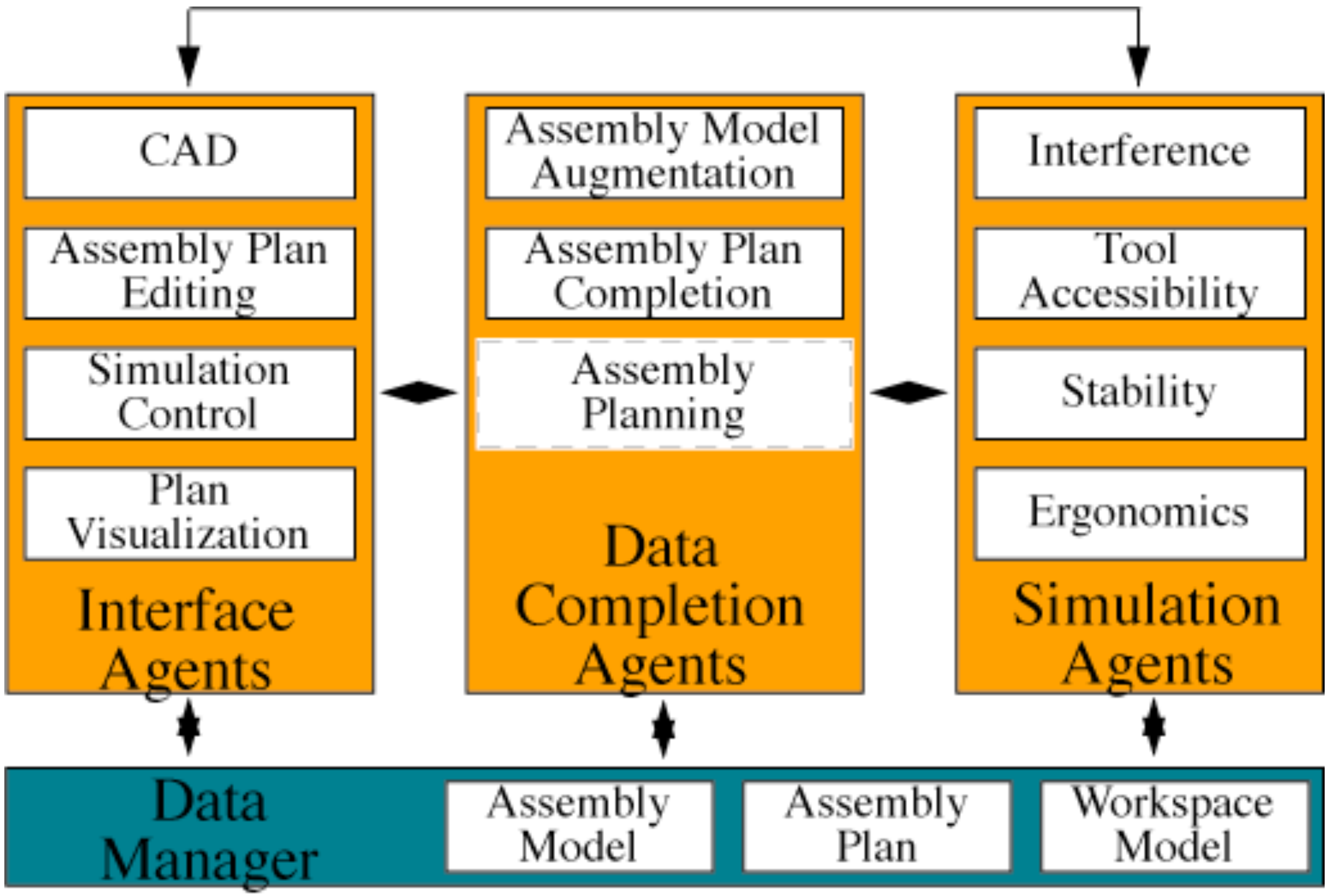
Intelligent Assembly Modeling & Simulation

The designer creates an assembly design using a commercial CAD package.

The goal of IAMS is to avoid this expensive and time-consuming process by facilitating assemblability checking in a virtual, simulated environment.



Intelligent Assembly Modeling & Simulation



Assembly planning

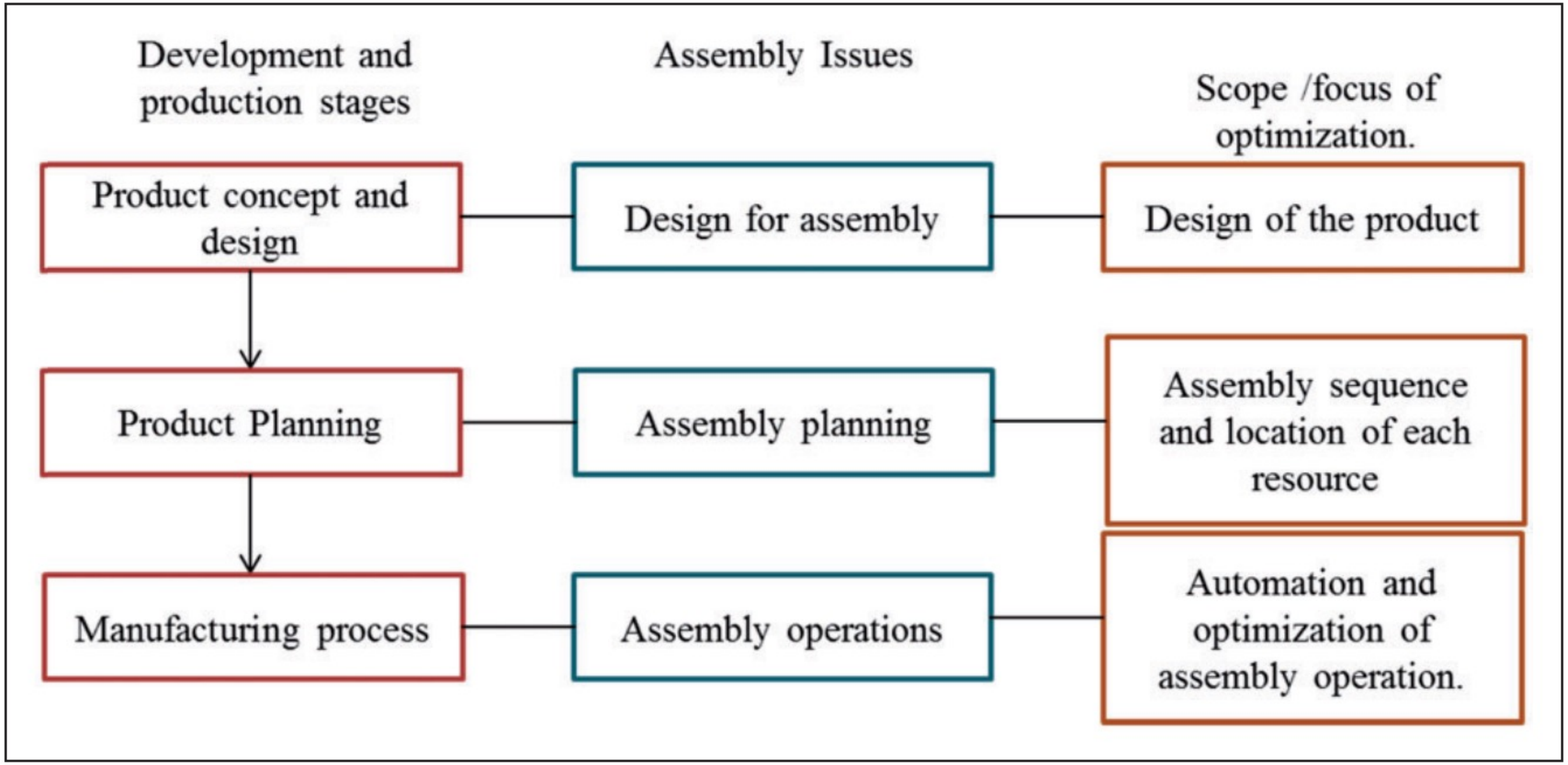
Assembly planning

Assembly can be done in two ways:

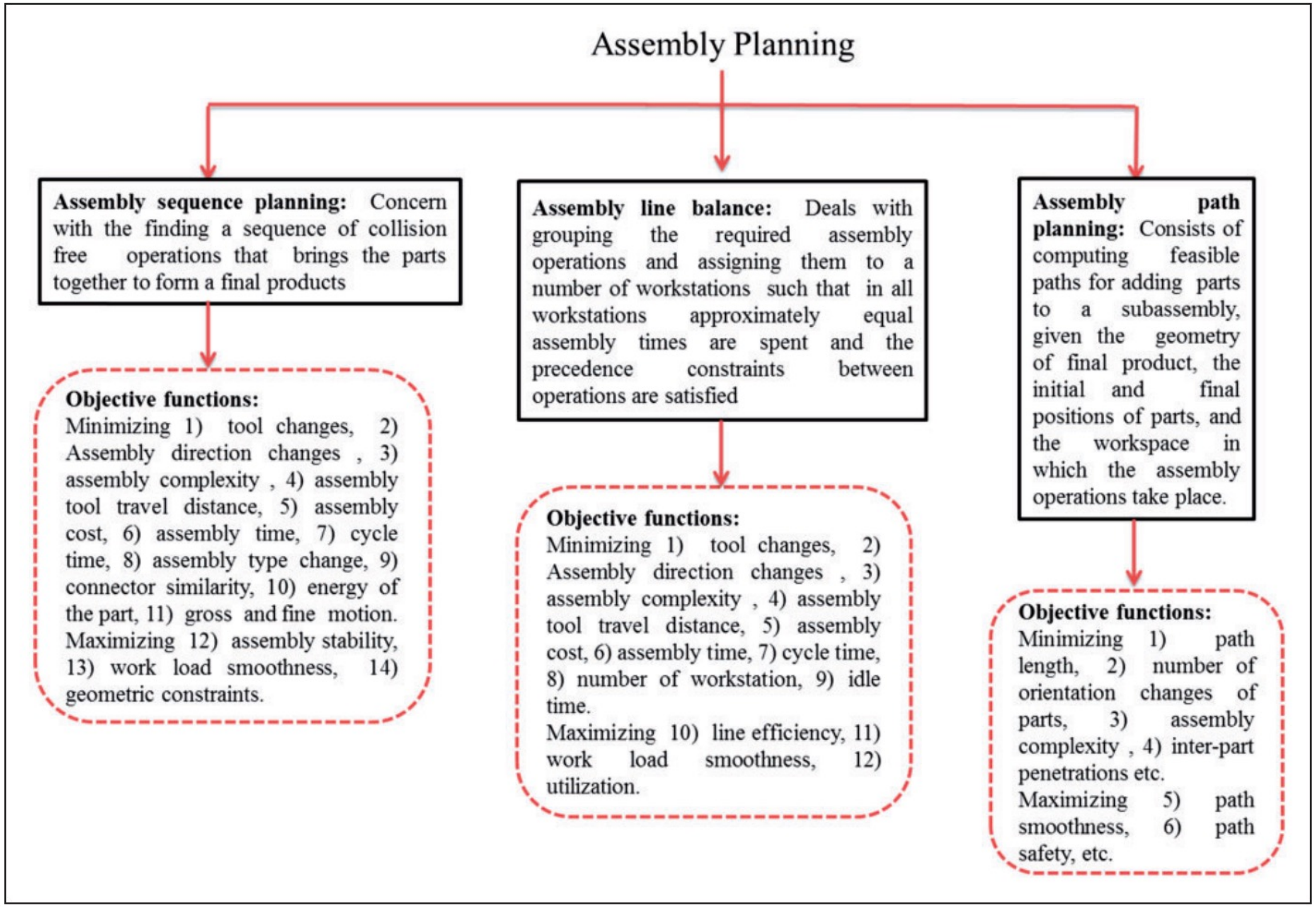
- linear assembly; in which parts are assembled one after the other.
- parallel assembly; in which sub-assemblies (a set of parts grouped together) are identified and joined simultaneously to obtain the final assembled product.

As the assembly process uses 50% of total production time and around 20–30% of manufacturing cost, efficient AP is required to reduce the time and cost of the manufacturing process.

Assembly related issues in different product development stages



Assembly planning and their classification



Assembly Sequence Planning

Assembly Sequence Planning (ASP) is one of important component in assembly planning.

ASP refers to a task for which planners, on the basis of their particular heuristics in assembling all the components of a product, arrange a specific assembly sequence according to the product design description.

Assembly Sequence Planning

Assembly optimisation in the production planning stage deals with determination of optimum assembly sequence and determination of optimum location of each resource.

Solving the Assembly Sequence Planning (ASP) problem is crucial because it will determine many assembly aspects including tool changes, fixture design and assembly freedom.

Assembly representation- directed graph

In assembly representation, directed graph is specifically known as precedence diagram since the graph represents the precedence relation of assembly.

Assembly representation- directed graph

An assembly can be described by a directed graph

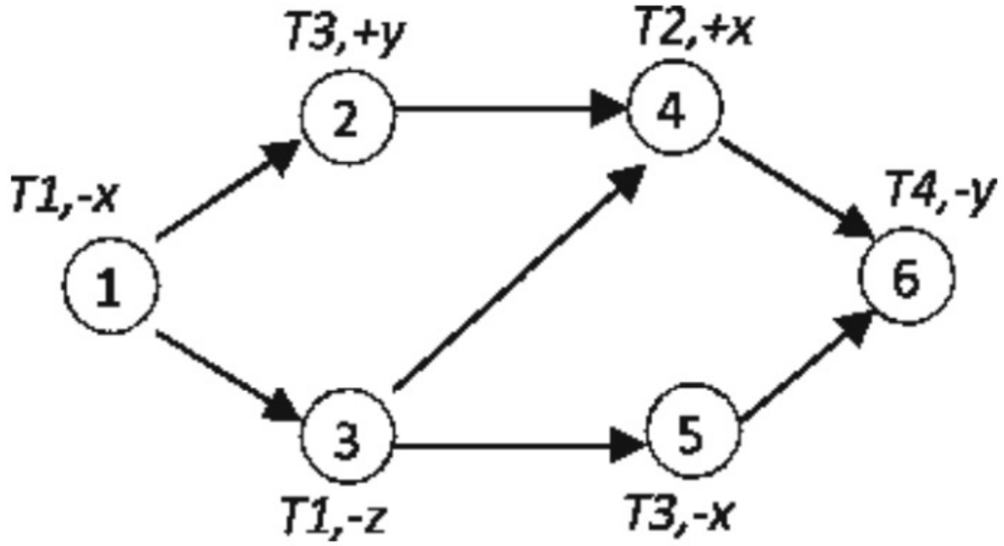
$$D = (P, C).$$

P : a finite nonempty set of vertices,

C : a set of edges connecting them.

Each vertex represents a component, and each edge represents a relationship between the two components. In some cases, the vertices and edges bring additional information such as assembly orientation, tool, assembly type and assembly time.

Assembly precedence diagram with additional information



T1, T2, T3 and T4 : represent the assembly tools

(+x, −x, +y, −y, +z, −z) : represents the assembly direction for a particular component

ASP Constraints

There are two types of constraints in assembly.

- **Absolute constraints** : refer to constraints that, if violated, lead to infeasible assembly sequence.
- **Optimisation constraints :** are the constraints that lead to lower quality of assembly sequences when violated.

Absolute constraints

Liaison data: This gives the information about contact details of the parts in the product.

Stability data: This gives the information about the stability of the parts in the product during assembly.

Geometric feasibility data: This gives the information in which direction one part assemble with the other without collision.

Mechanical feasibility data: This gives the information whether any two parts can be assembled in the presence of the other part.

Absolute constraints

The absolute constraints that are usually considered include

- **Precedence constraints** : shows the relation of predecessor and successor components for assembly process.
- **Geometrical constraints** : is about assembling the components without any collision.

Absolute constraints
Precedence constraint

The precedence constraint cannot be violated, otherwise the infeasible assembly sequence will be generated. Precedence constraint can be represented in precedence diagram or in matrix form. In this matrix, when part i must be assembled after part j, $P(i, j) = 1$. Otherwise, the matrix will be left empty.

i	j					
	1	**2**	**3**	**4**	**5**	**6**
1						
2	1					
3	1					
4	1	1	1			
5	1		1			
6	1	1	1	1	1	

Absolute constraints
Geometrical constraints

All valid assembly sequences must meet geometric constraints for a given structure.

For each pair of components (Pi, Pj), the matrix records directions in which Pi can be assembled without colliding with Pj.

Then, a set of valid assembly directions, for each (Pi, Pj) is defined, as the moving wedge of Pi with respect to Pj , denoted by $MW(Pi, Pj)$.

They compute moving wedges for all pairs of components and store all moving wedges in the MW matrix.

Assembly Line Balancing

Assembly Line Balancing is the decision problem of optimally partitioning the assembly work among the stations with respect to some objective.

ALB was first mathematically formulated by Salveson in 1955.

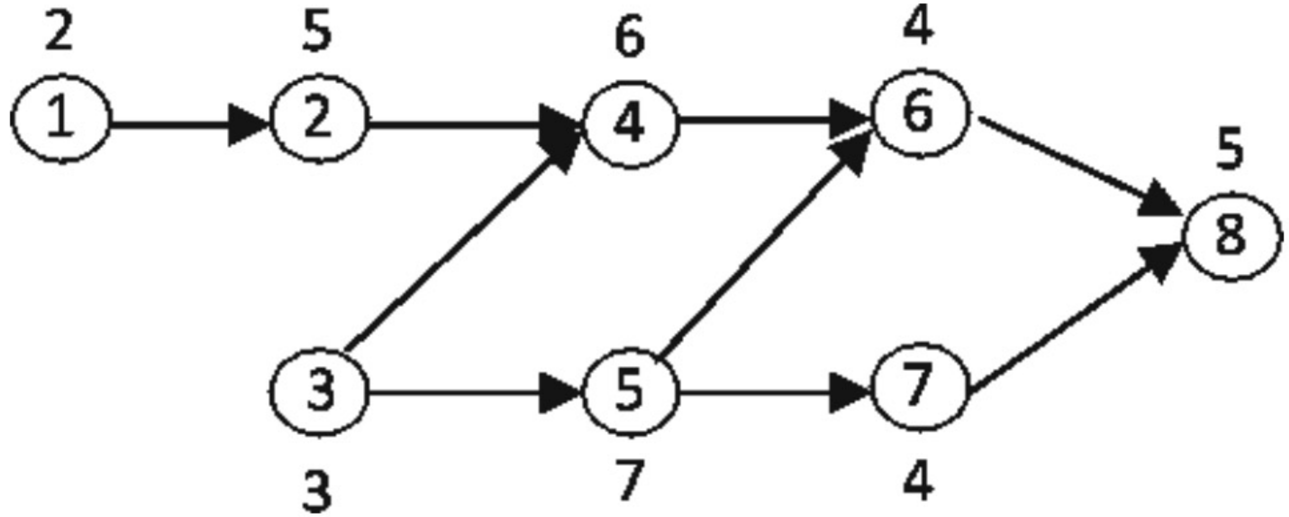
ALB problem into two categories:

- ➢Simple Assembly Line Balancing Problem (SALBP)
- ➢Generalised Assembly Line Balancing Problem (GALBP)

Assembly Line Balancing

The simple ALB problem can be represented in precedence diagram that contain n vertices and a set of edges.

Each vertex represents an assembly task. Meanwhile, the vertices weight shows the assembly time and the edges reflecting the successor tasks.



Precedence diagram for ALB

Abrrivations

ASP	Assembly Sequence Planning
ALB	Assembly Line Balancing
EAM	Enriched Assembly Model
GALB	Generalised Assembly Line Balancing
HAG	Hierarchical assembly graph
IAMS	Intelligent Assembly Modeling & Simulation
KC	key characteristics
PLM	Product Lifecycle Management
SALB	Simple Assembly Line Balancing