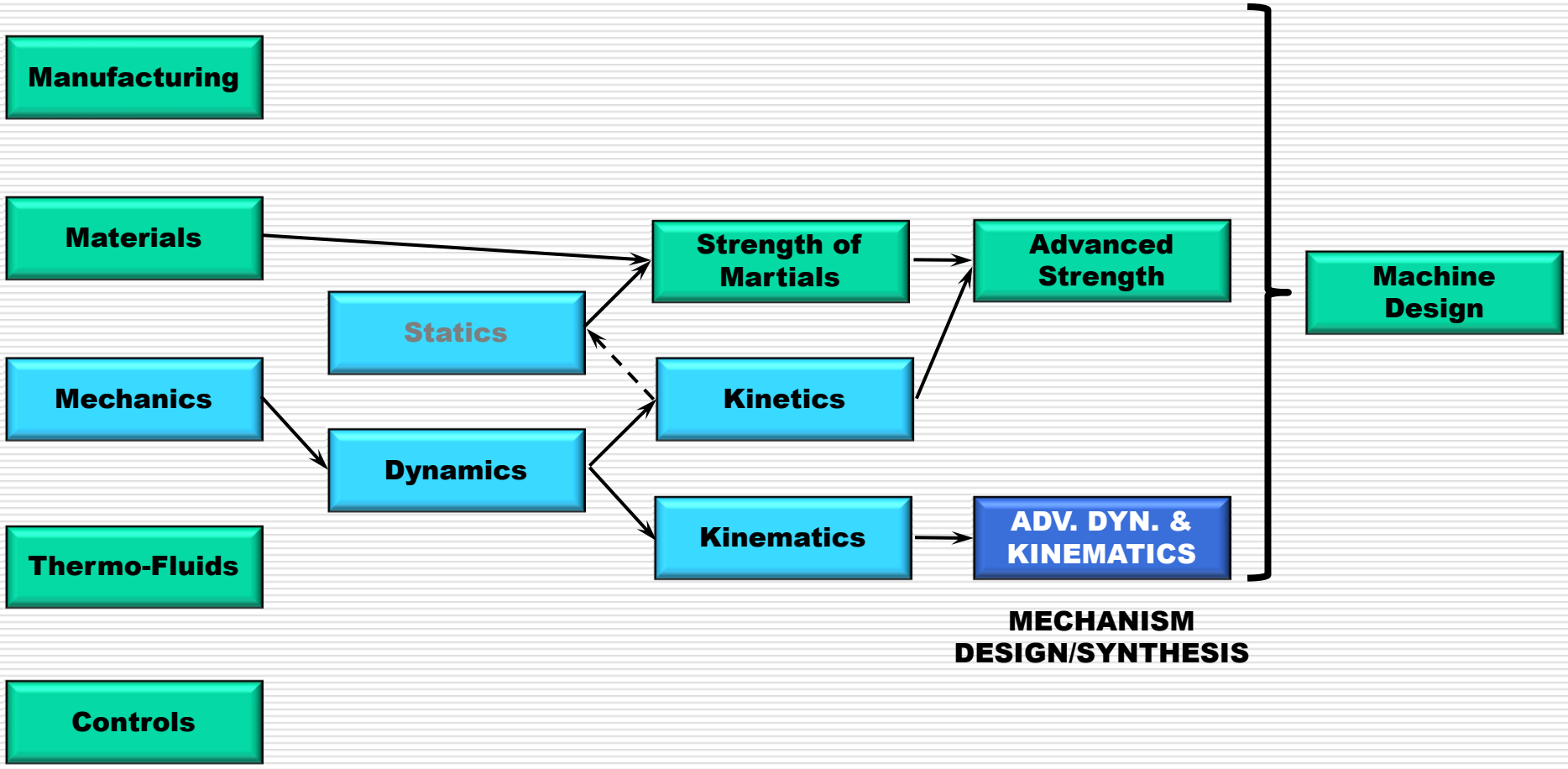
INTRODUCTION TO MECHANISM SYNTHESIS

- Mechanics Place in Science
- Mechanisms and Structures
- Number Synthesis
- Paradoxes and Isomers
- Transformations and Inversions
- Grashof's Law

The Ultimate Goal is to Synthesize Machine Elements



Machines/Kinetics and Mechanisms/Kinematics

- **Machines:** A combination of resistant bodies so arranged that by their means the mechanical forces of the nature can be compelled to do work accompanied by certain determinate motions.

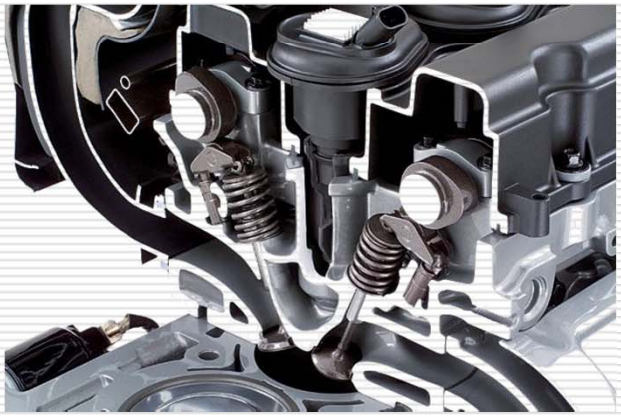
- **MECHANISMS:** An assemblage of resistant bodies, connected by movable joints, to form a closed kinematic chain with one link fixed and having the purpose of transforming motion.

- **Structures:** An assemblage of resistant bodies connected by joints (or not) that do no work, and do not transfer motion. It is intended to be rigid.

Synthesis of Several Mechanisms will be Considered

Linkages

Gears

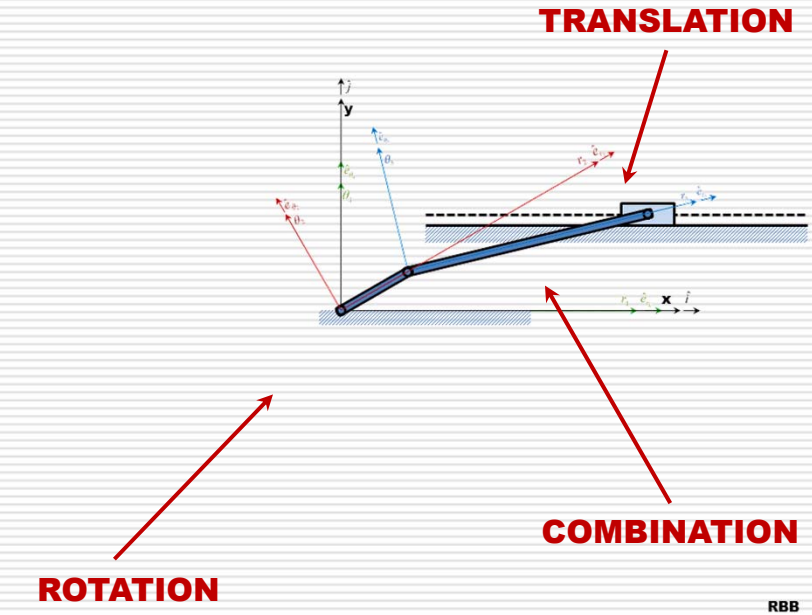


CAMs

Mechanisms are Synthesized to Produce Various Types of Motion

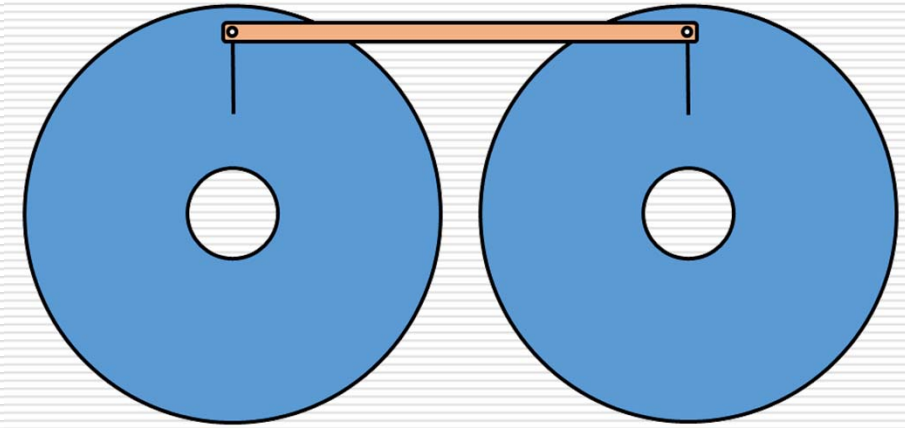
PLANAR MOTION: All motion contained to one geometric Plane or Parallel Planes.

- **Rectilinear Translation: All Points of the body move in parallel straight line paths.**
- **Rotation: Each point the body remains a constant distance from a fixed axis that is perpendicular to the plane of motion.**
- **Rotation and Translation: Combination of the above two.**



Curvilinear Translation a Special Case of Translation

Curvilinear Translation: The paths of the points are identical curves parallel to a fixed plane.

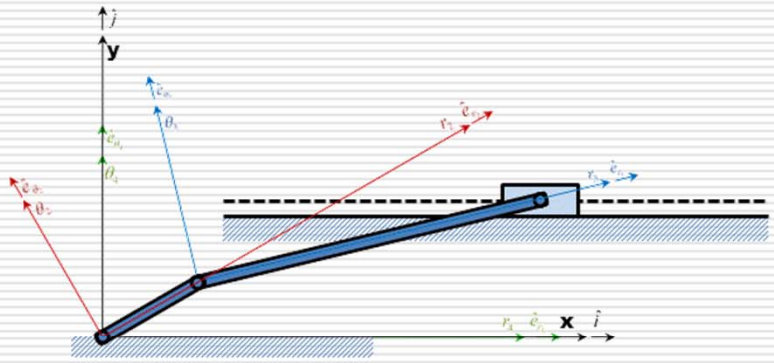


Non-Planar Motion Can Also Be Generated By Mechanisms

- **Helical Motion:** each point of the body has motion of rotation about a fixed axis and at the same time has translation parallel to the axis.
- **Spherical Motion:** each point of the body has motion about a fixed point while remaining at a constant distance from it.
- **Spatial Motion:** the body moves with rotations about three non-parallel axes and translates in three independent directions.

Cycle, Period, and Phase of Motion

- **Cycle:** When the parts of a mechanism have passed through all the possible positions they can assume after starting from some simultaneous set of relative positions and have returned to their original relative positions.

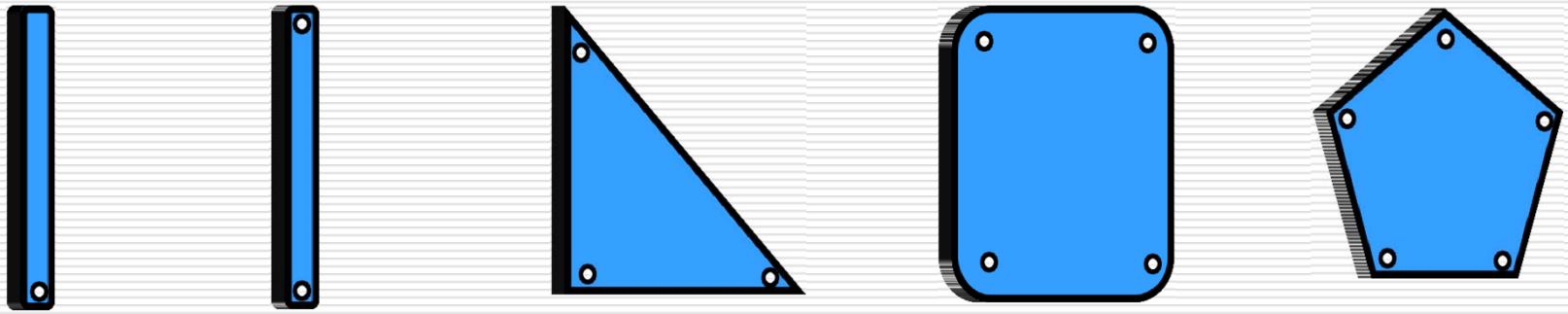


- **Period:** The time required for a cycle of motion.

- **Phase:** The simultaneous relative position of a mechanism at a given instant during a cycle.

RBB

A Link Is A Rigid Body Having Two or More Nodes



Unary Binary Ternary Quaternary Pentagonal

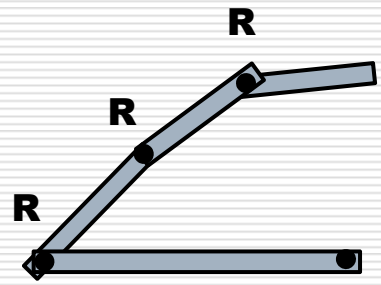
Nodes/Pairing Elements: Points at which links can be attached. The order of the link is determined by the attachments used.

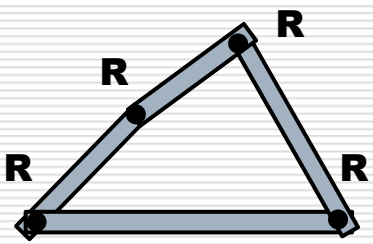
Joints/Kinematic Pairs: Allows relative motion between links.

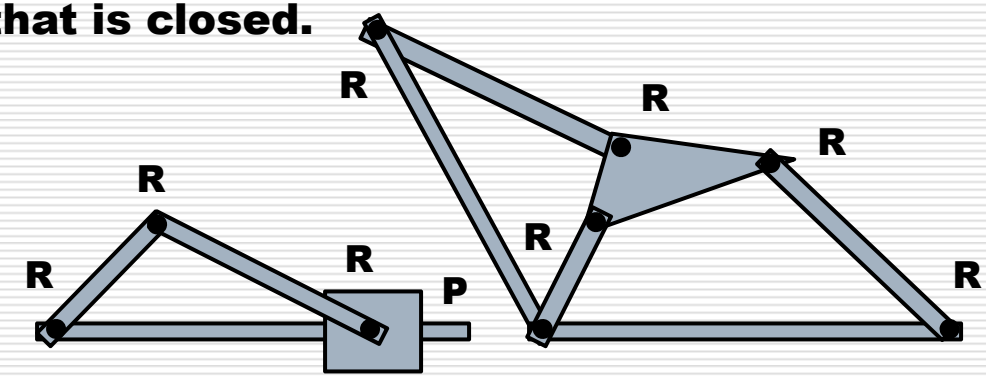
Joint Classes: a kinematic pair is of the j^{th} class if it diminishes the relative motion of linked bodies by j Degrees of Freedom (DoF)

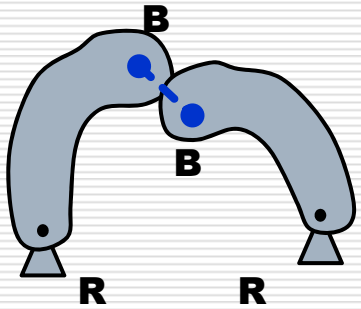
Kinematic Chains are Formed by Connecting Links with Pairs

- **Closed Kinematic Chain:** A chain that forms one or more closed loops.
- **Open Kinematic Chain:** A chain with one or more open loops.
- **Simple-Closed Chain:** Chain consisting of entirely binary links and is closed.
- **Compound Closed Chain:** Chain including other than binary links that is closed.





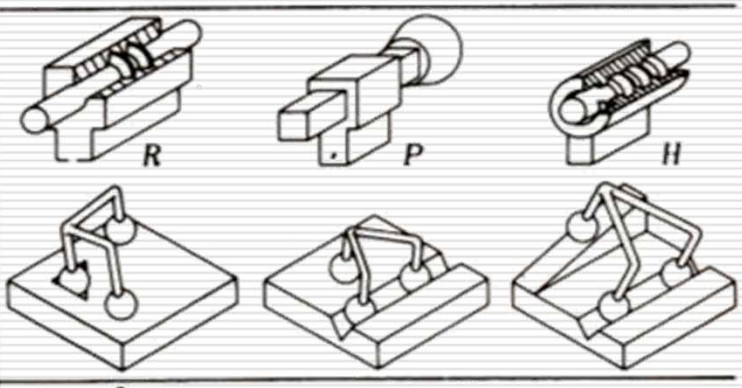
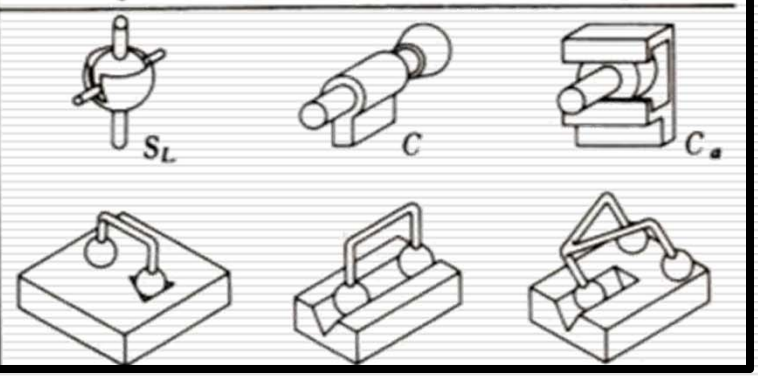




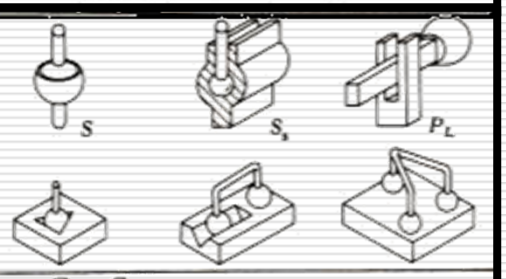
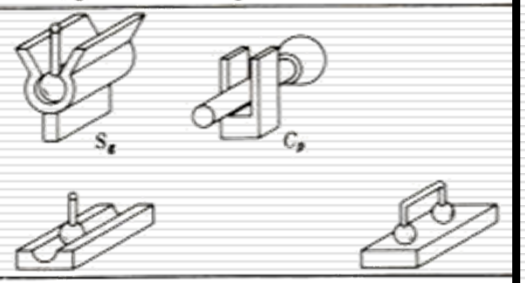
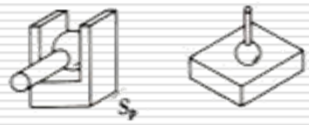
Joint Classification, Kinematic Pairs

- Type of contact between elements
  - Line
  - Point
  - } Higher Pairs
  - Surface → Lower Pairs
- Degrees of Freedom Allowed
- Type of Physical Closure
  - Force
  - Form
- Number of Links Joined (Order)

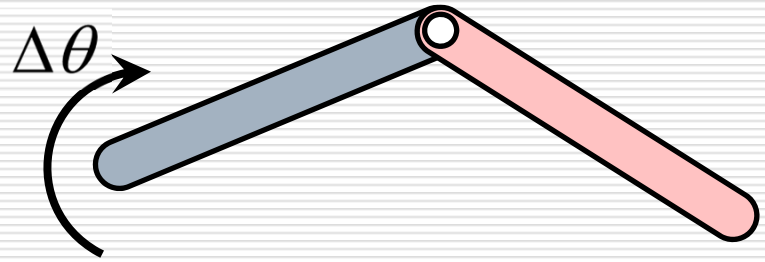
1 and 2 DOF Kinematic Pairs as Defined by Reuleaux

Class of kinematic pairs	Degrees of freedom	Number of point contacts	Name of kinematic pair and its symbol	Kinematic pairs, form-closed and force-closed
I	1	5	Revolute–R Prismatic–P Helical–H	
II	2	4	Slotted spheric–S_L Cylinder–C Cam–C_a	

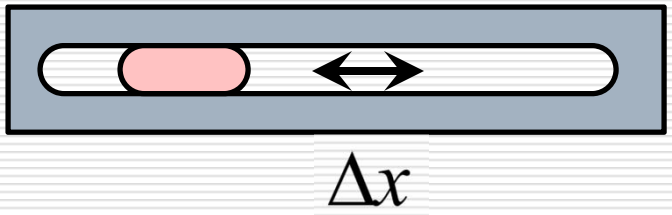
3, 4, and 5 DOF Kinematic Pairs as Defined by Reuleaux

Class of kinematic pairs	Degrees of freedom	Number of point contacts	Name of kinematic pair and its symbol	Kinematic pairs, form-closed and force-closed
III	3	3	Spheric pair – S Sphere-slotted cylinder – S_S Plane pair – P_L	
IV	4	2	Sphere-groove – S_g Cylinder plane pair – C_p	
V	5	1	Sphere-plane – S_P	

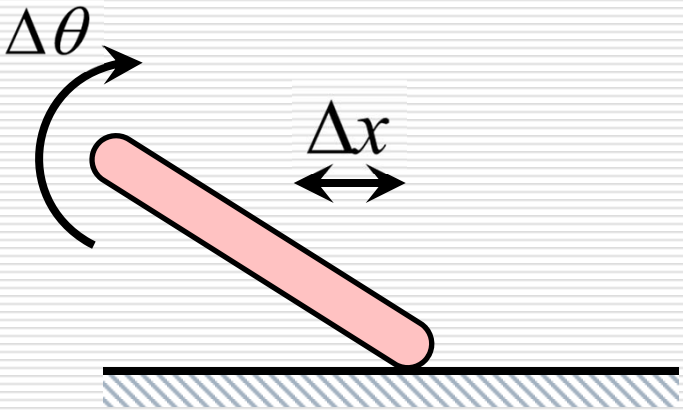
Joint Closure Classified as Lower Pairs and Higher Pairs



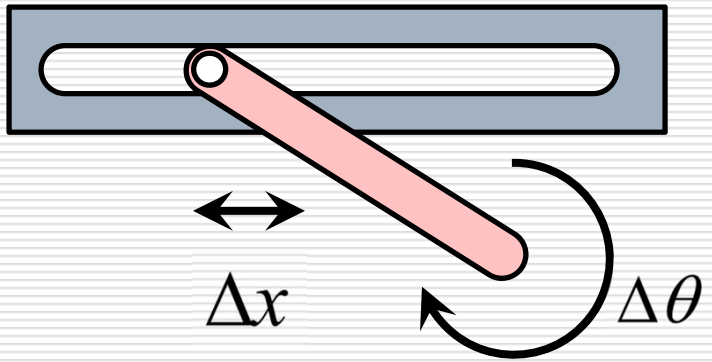
Form Closed, Rotating FULL Pin Joint



Form Closed, Translating FULL Slider Joint



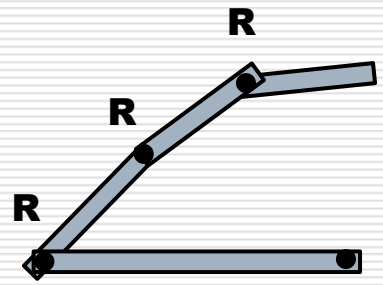
Force Closed,
Link against a plane HALF Joint

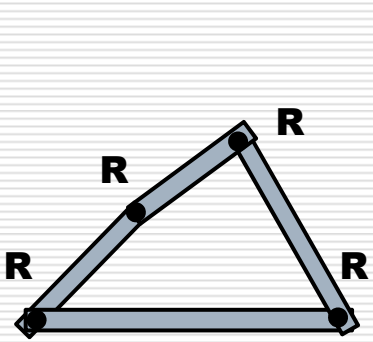


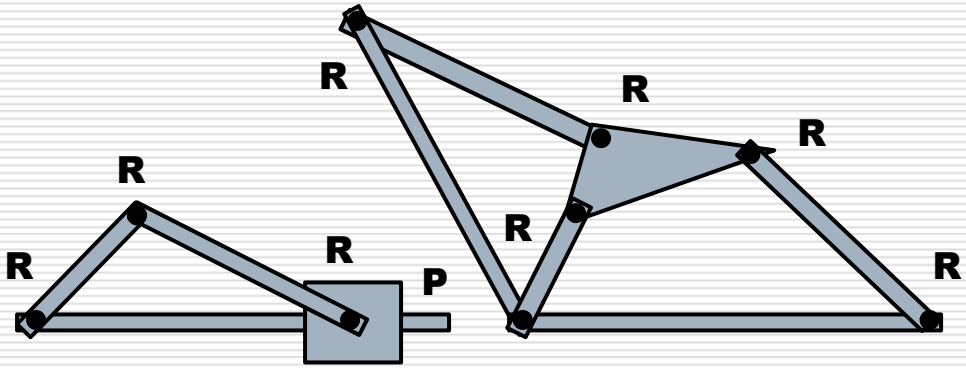
Form Closed,
Pin in Slot HALF Joint

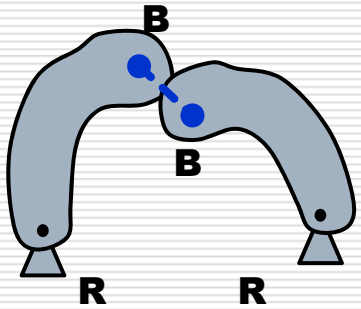
Degrees of Freedom or Mobility

- The number of inputs needed to provide in order to create a predictable output
- The number of independent coordinates required to define its position



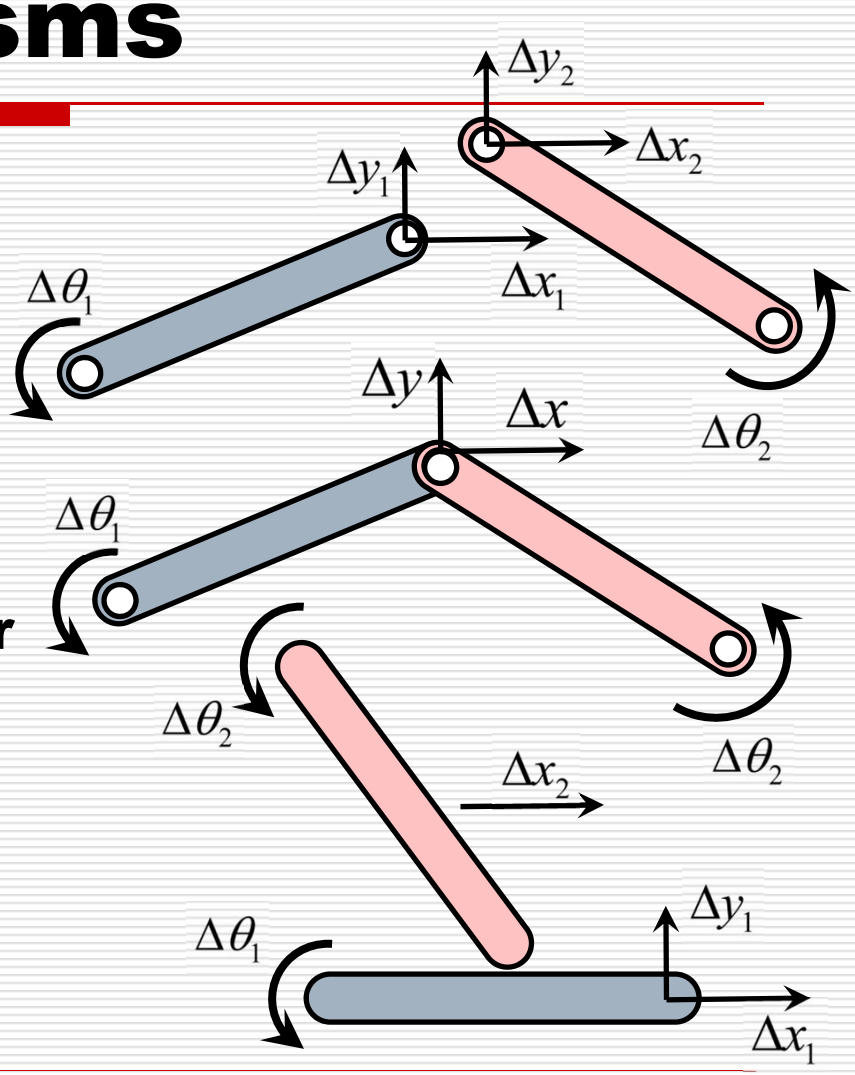






Planar Mechanisms

- Each link has 3 DoF when moving relative to a fixed link
- n link planar mechanism (one link is considered fixed) has 3(n-1) degrees of freedom before joints are connected
- Connecting a revolute pair
  - 1 DoF → 2 constraints
  - 2 DoF → 1 constraint
- Mobility of Mechanism
  - Constraints of all joints minus total DoF of unconnected links



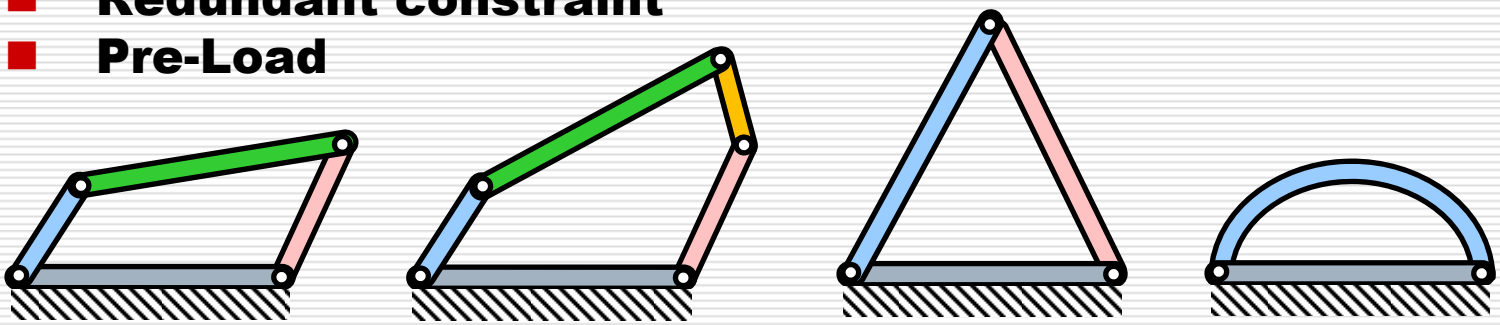
Mobility

- L- number of links
- M- mobility of planar n-link mechanism
- j_1- number of 1 DoF pairs
- j_2- number of 2 DoF pairs
- Kutzbach Criterion

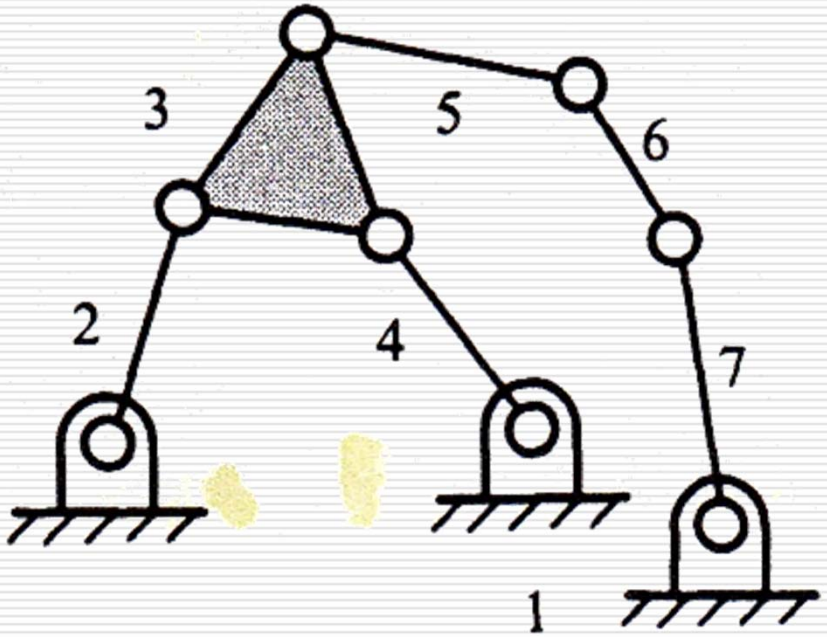
$$M = 3 \cdot (L - 1) - 2 \cdot j_1 - j_2$$

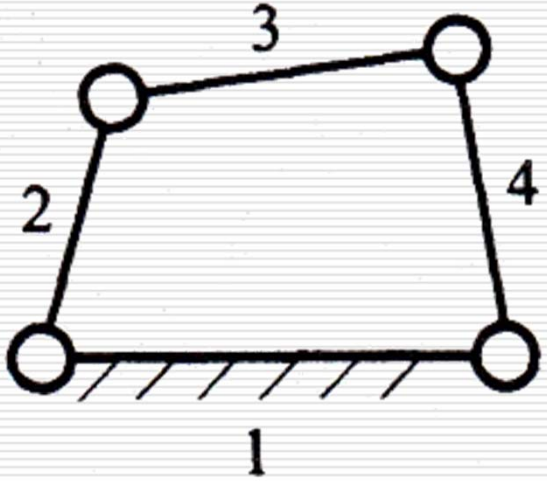
Kutzbach Criterion

- M=1
  - Mechanism can be driven by a single input direction
- M=2
  - Two separate input motions are necessary to produce constrained motion for the mechanism
  - Differential Mechanism
- M=0
  - Motion is impossible and the mechanism is a structure
- M=-1
  - Redundant constraint
  - Pre-Load

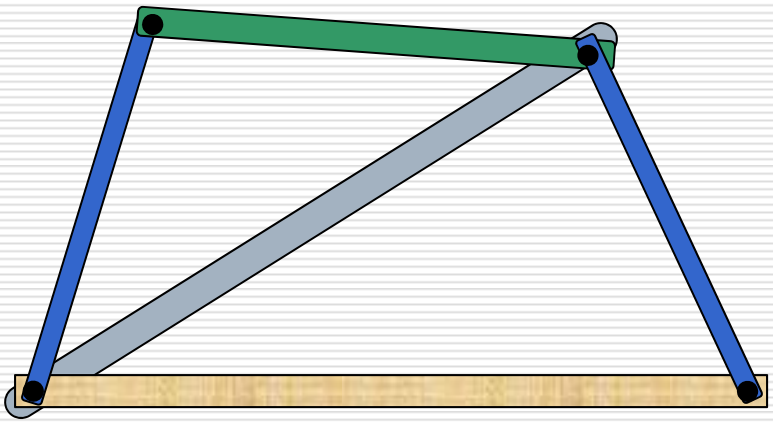


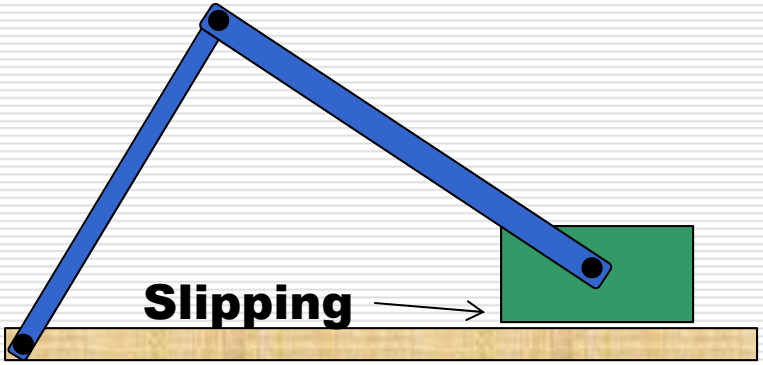
Calculate the Mobility



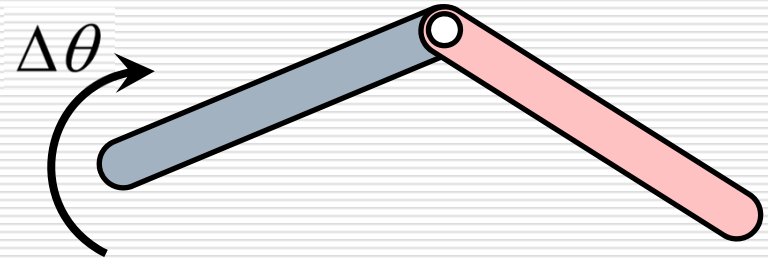


Calculate the Mobility

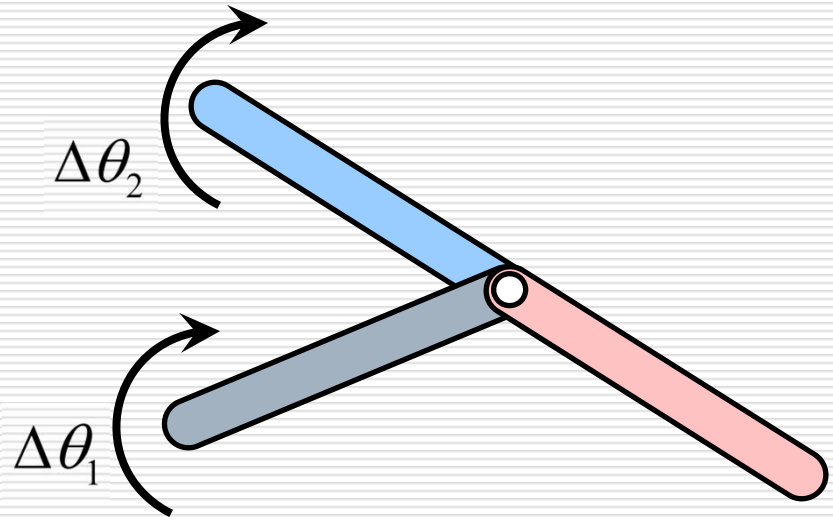




Order of a Joint is One Less than the Number of Links Joined

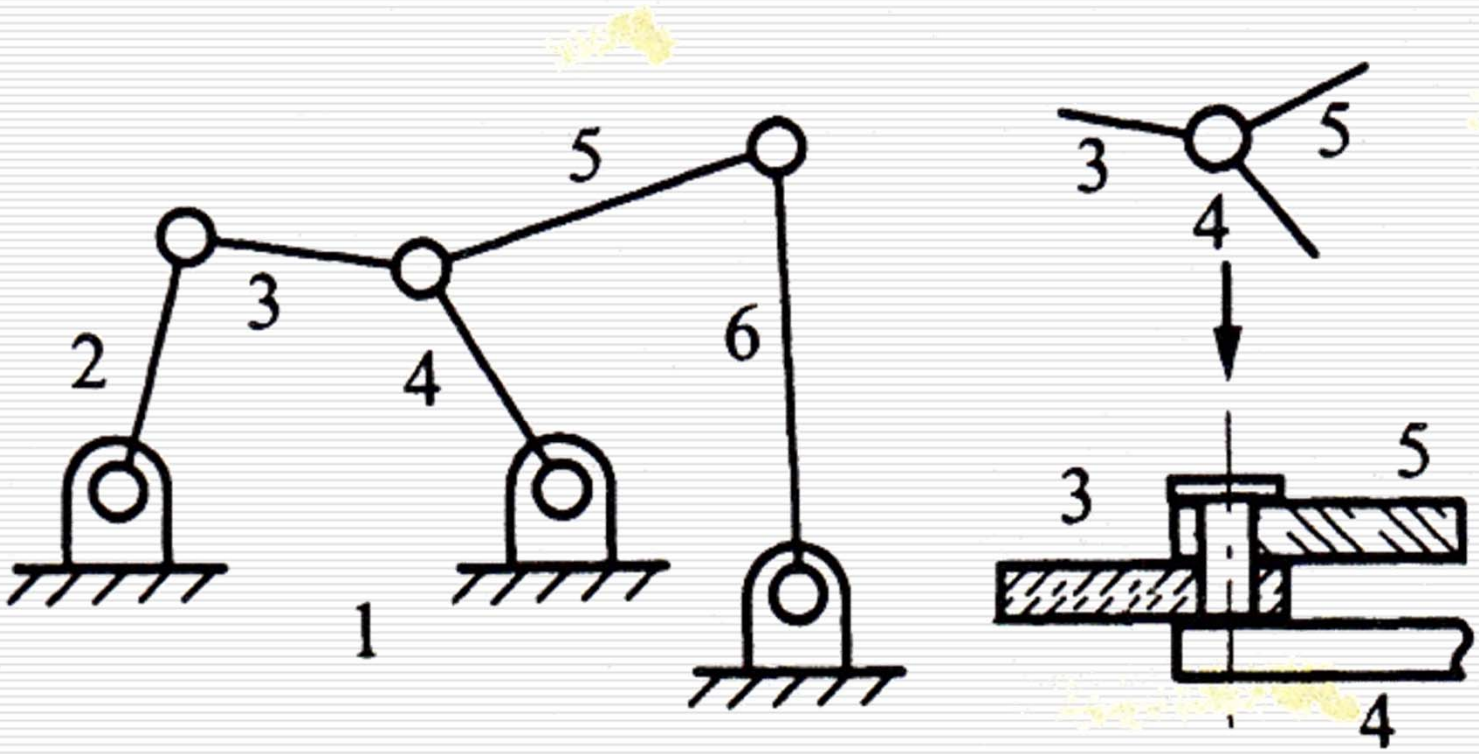


First order pin Joint

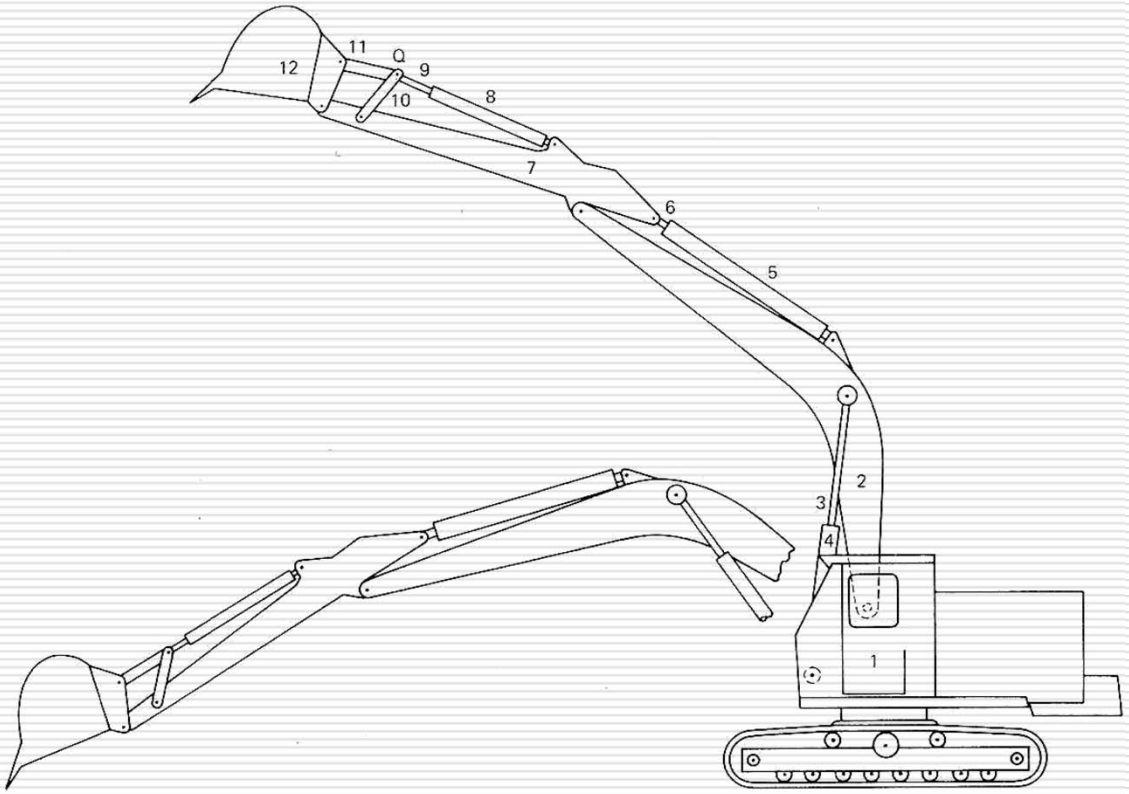


Second order pin Joint

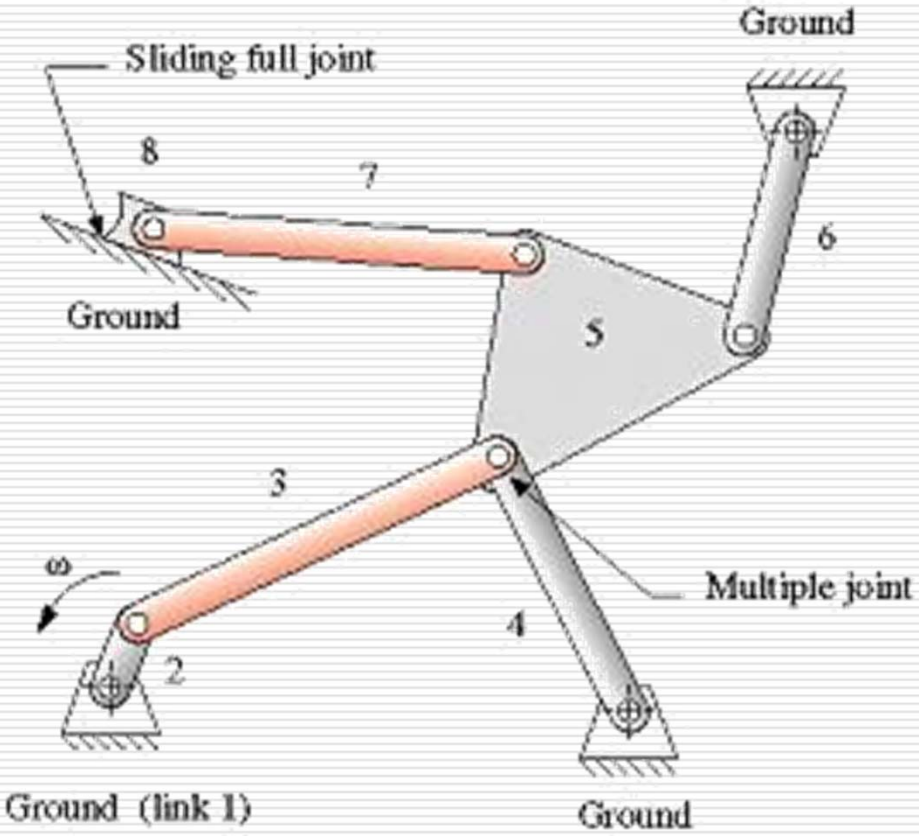
Example



Example

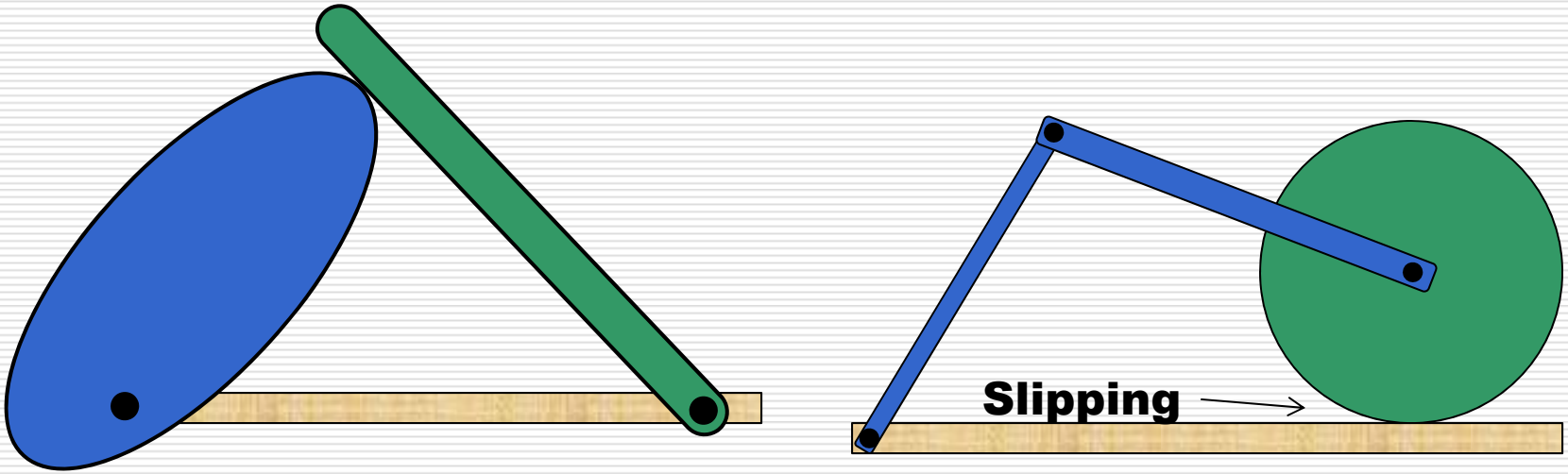


Example

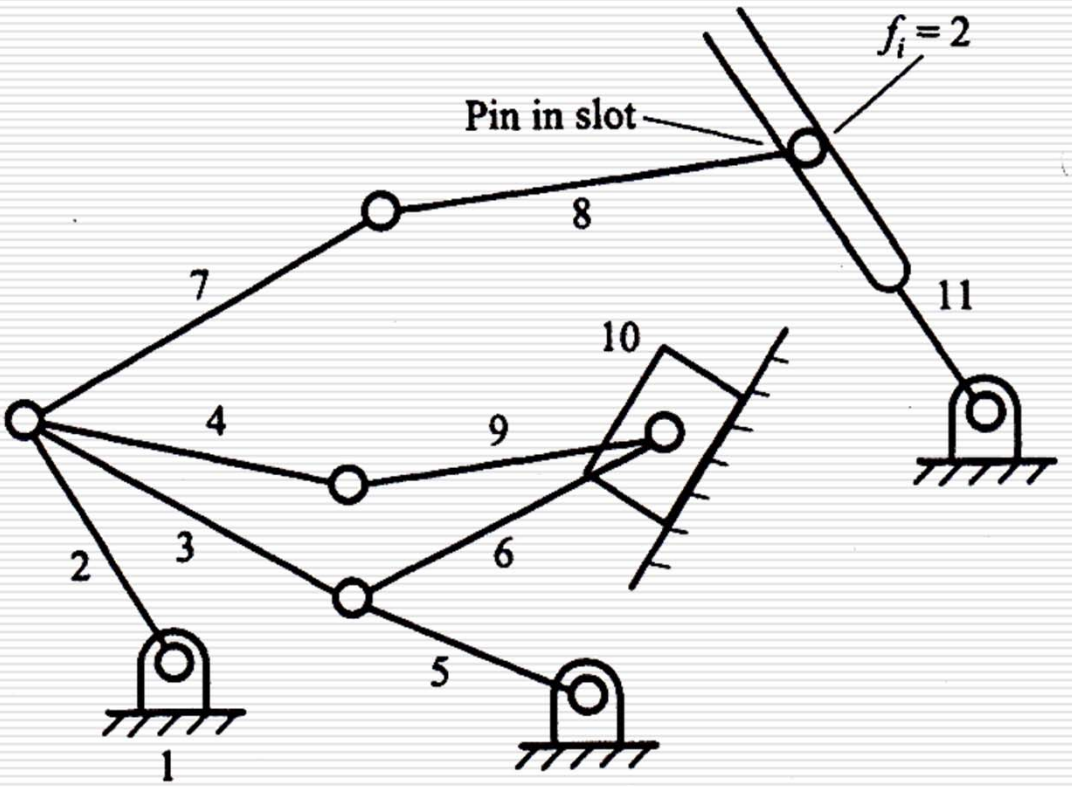

Ground
Sliding full joint
8
7
6
Ground
5
3
ω
Multiple joint
4
2
Ground (link 1)
Ground

Kutzback Criterion for Half Joints

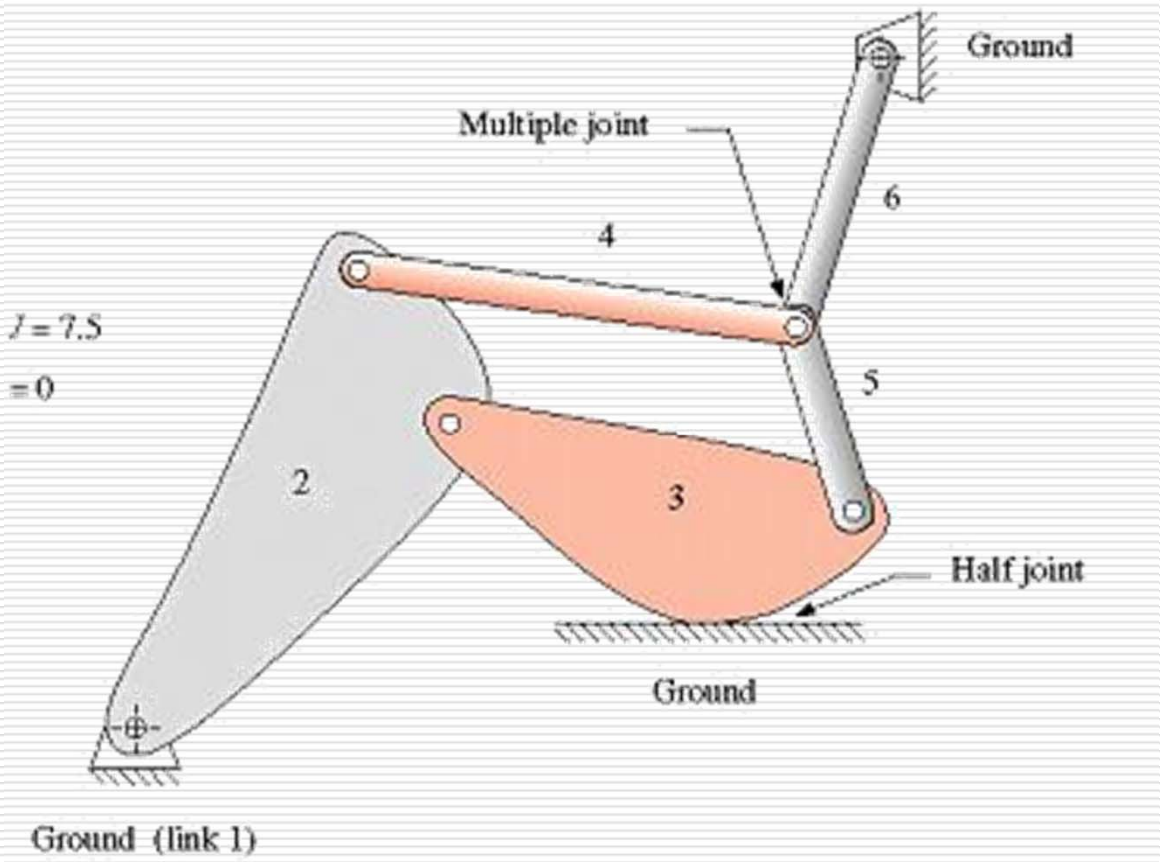
- Particular attention should be paid to the contact between the wheel and the fixed link



Example



Example


Ground
Multiple joint
6
4
J = 7.5
= 0
5
2
3
Half joint
Ground
Ground (link 1)

Spatial Mechanism

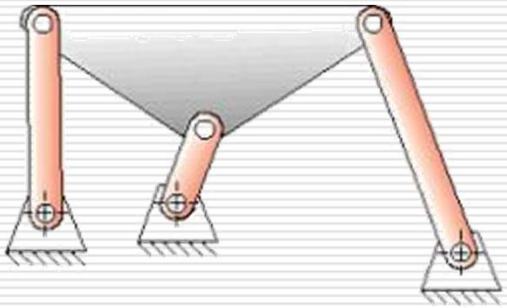
- **Kutzbach Criterion**

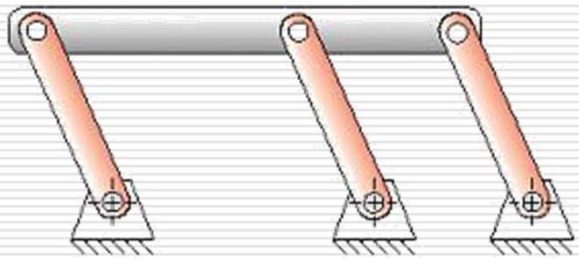
$$M = 6 \cdot (L - 1) - 5 \cdot j_1 - 4 \cdot j_2 - 3 \cdot j_3 - 2 \cdot j_4 - j_5$$

- **Where**
  - j_3- 3 Dof joints
  - j_4- 4 Dof joints
  - j_5- 5 Dof joints

Kutzback Criterion Paradoxes

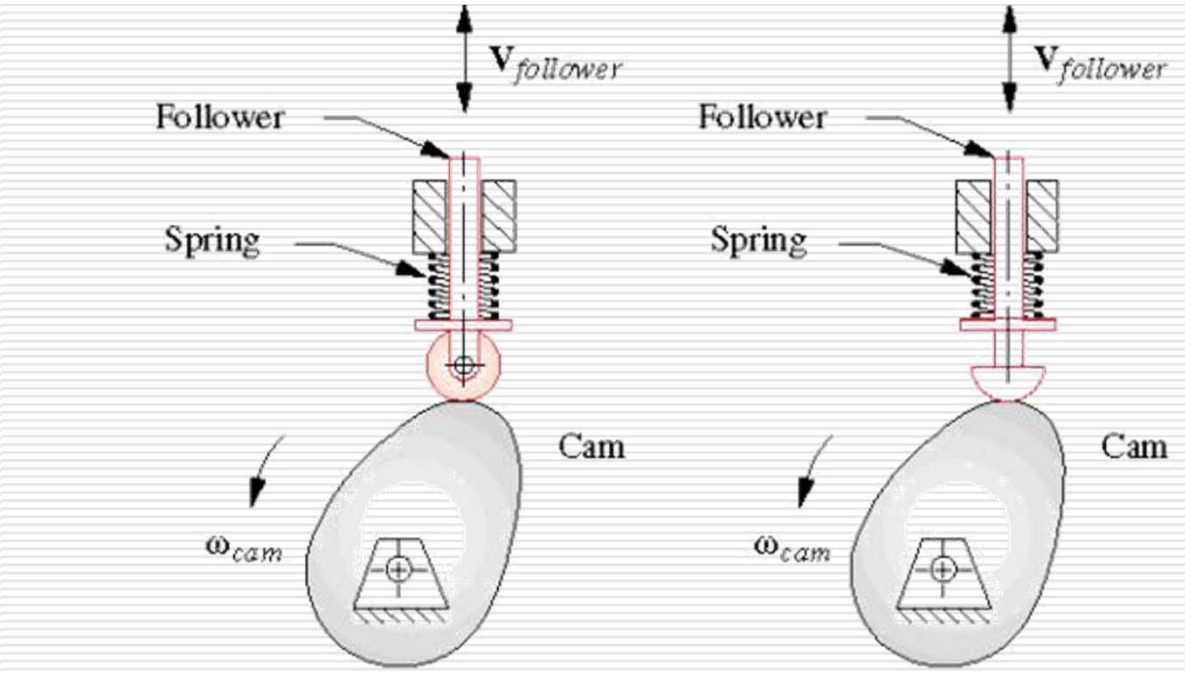
- Over-constrained Linkage with Redundant Constraint





Kutzback Criterion Paradoxes

- Passive or Idle Degree of Freedom



Calculate the Mobility