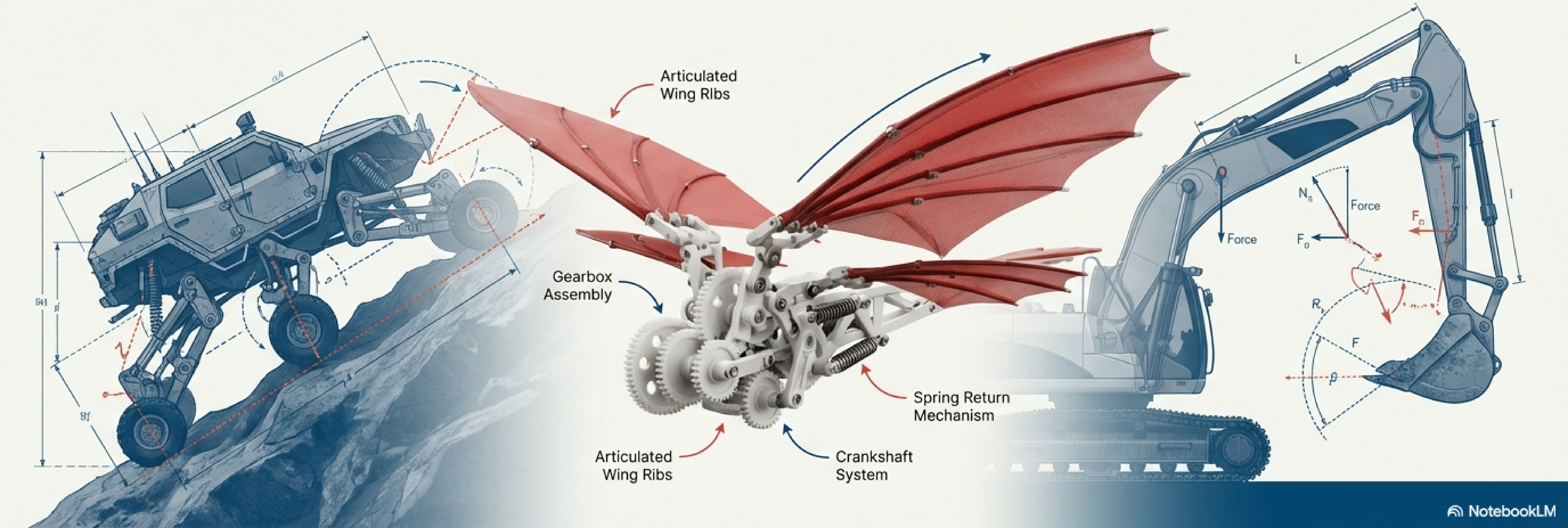
ME 3751: The Art and Science of Motion

An Introduction to Kinematics and Mechanism Design



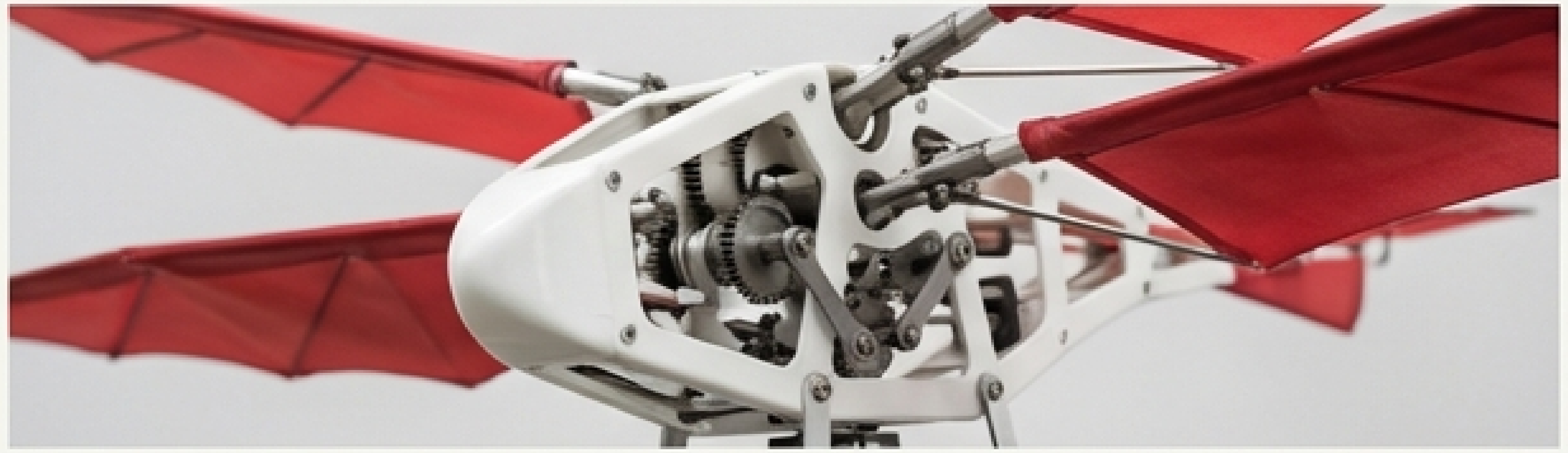
From Brute Force to Intricate Paths: The Power of Mechanisms

Force Amplification

Magnifying human effort to securely lock onto a workpiece.

Path Generation

Generating **precise straight-line foot paths** for mobility on uneven terrain.



Motion Generation

Creating complex, multi-axis motion to mimic nature and achieve flight.

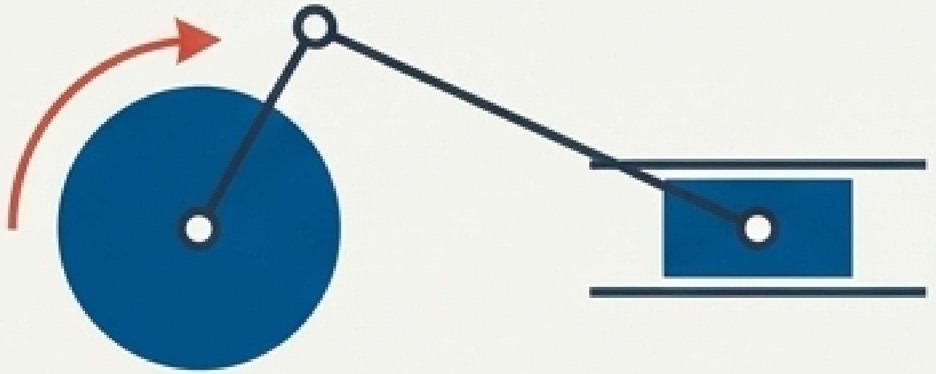
Operator Control

Providing **versatile, controlled bucket paths** for digging and construction.

A mechanism is the **skeleton of a machine**—it's the arrangement of parts designed to **produce a specific, desired motion**. This course is about learning to design that skeleton.

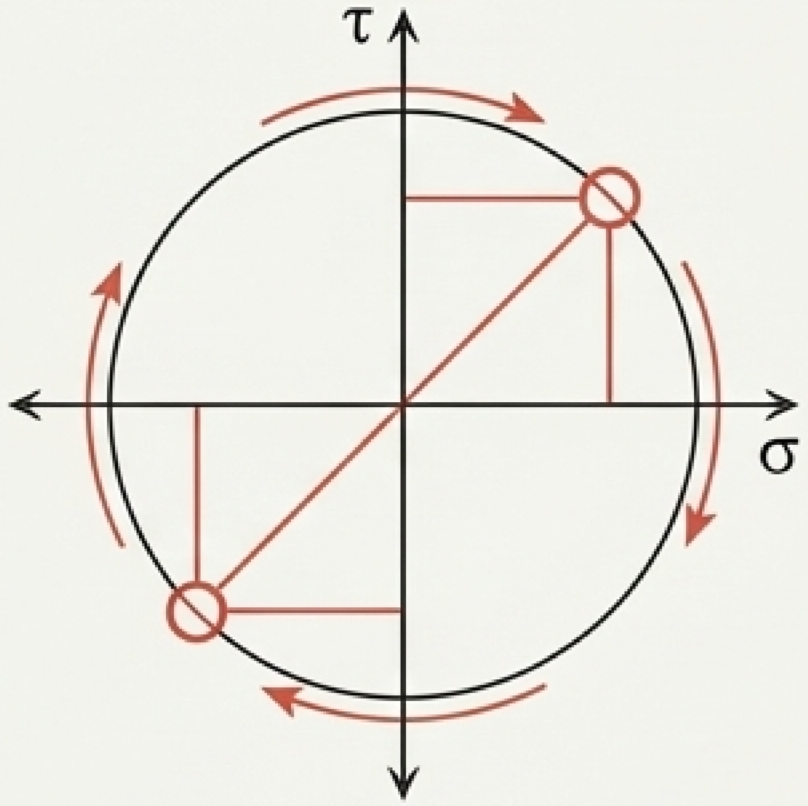
The Three Pillars of Machine Design

Part I: Kinematics & Mechanisms (This Course)



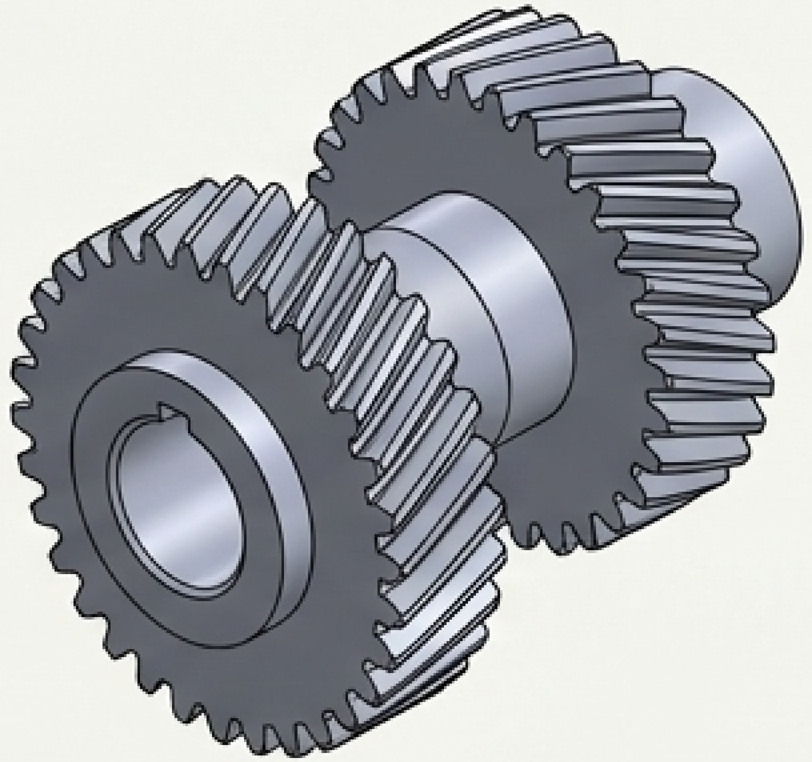
How does it move?
The Geometry of Motion.

Part II: Strength of Materials



Will it break?
Forces & Stresses.

Part III: Machine Element Design



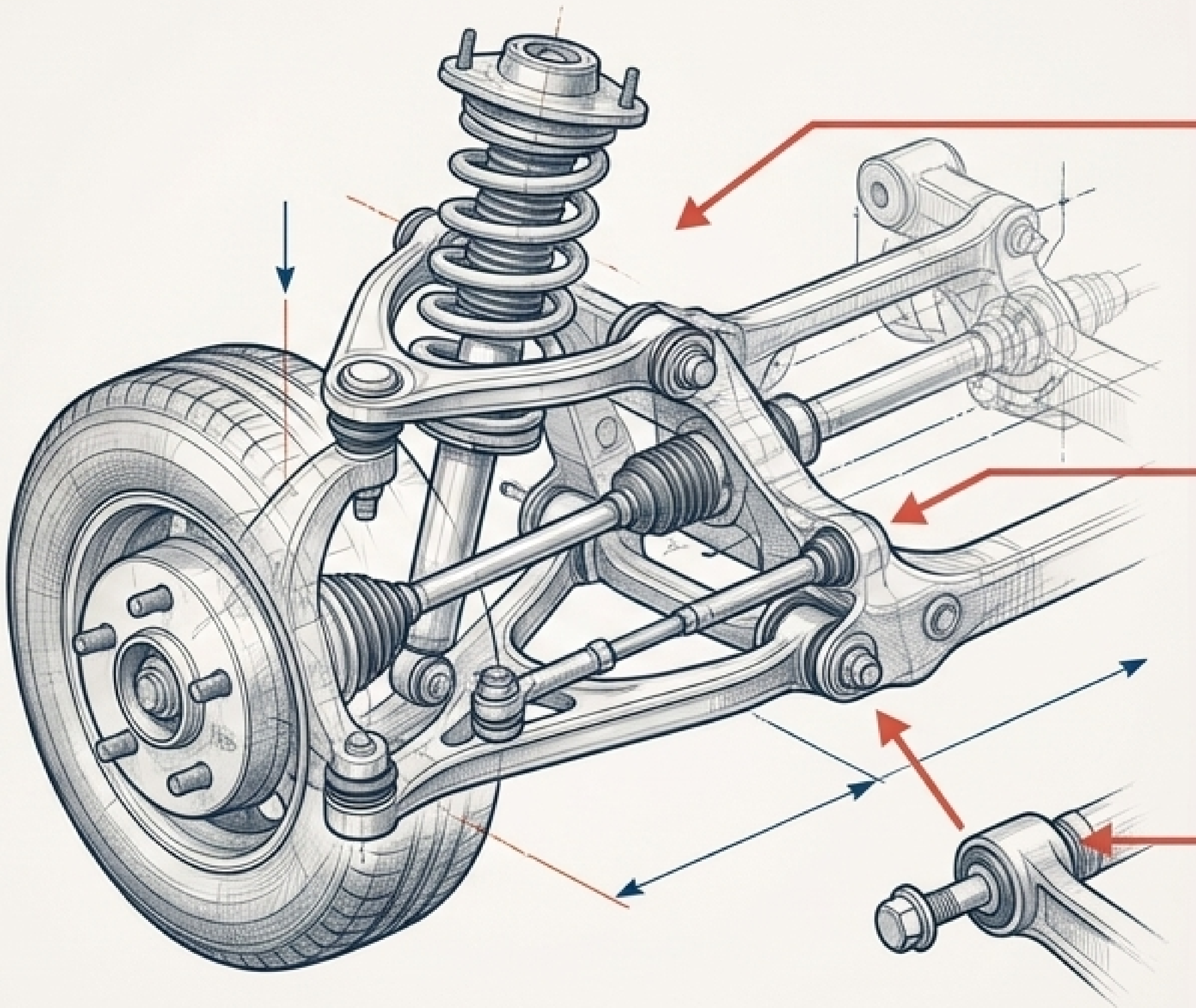
How do we build it?
Components & Assembly.

Kinematics is the first fundamental pillar. Before we worry if a part is strong enough (Kinetics) or what bearing to use (Elements), we must first define and control its motion. Mastering kinematics is the starting point for all great machine design.

The Language of Motion: Machines vs. Mechanisms

Machine: Mechanism + Actuators + Controls + Structure

Mechanism: The heart of the machine, focused purely on transferring motion.



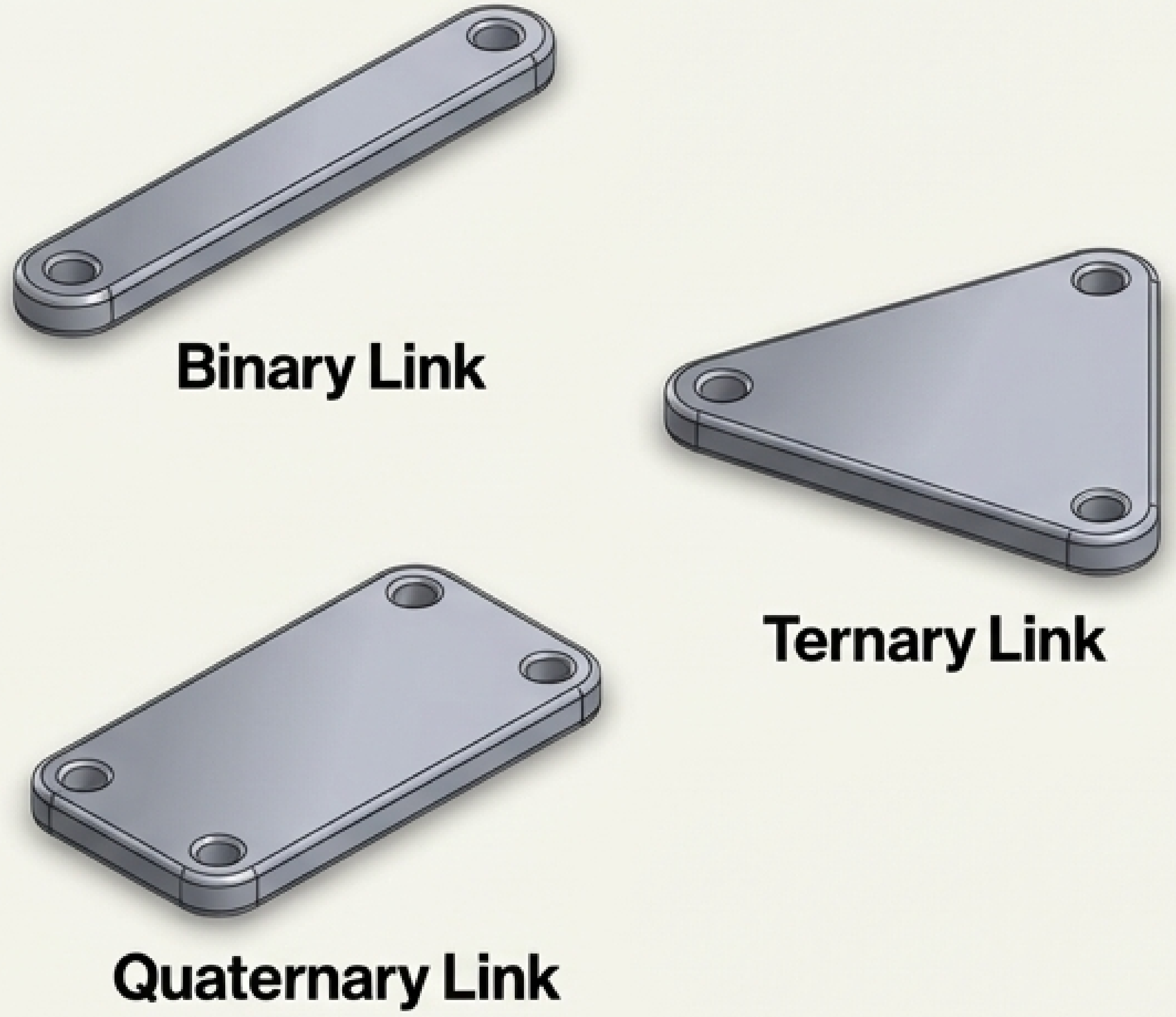
Machine - A system of elements arranged to transmit motion and energy.

Mechanism - The core assemblage of rigid members connected by joints that guides the motion.

Machine Element - The standardized components that hold it together.

A car is a machine. The suspension that controls the wheel's movement is a mechanism.
In this class, we are laser-focused on the Mechanism. We will master the design of motion itself.

The First Building Block: The Link



- A **Link** is a rigid body that is part of a mechanism.
- For kinematic analysis, we assume links are perfectly **rigid** and **massless**.
- A link's function is defined by the number of connection points (nodes for joints) it possesses.
  - **Binary Link:** Connects to 2 other links.
  - **Ternary Link:** Connects to 3 other links.
  - **Quaternary Link:** Connects to 4 other links.

Think of links as the bones of our mechanism's skeleton. Their exact shape doesn't matter yet; what matters is their rigidity and how many other links they connect to.

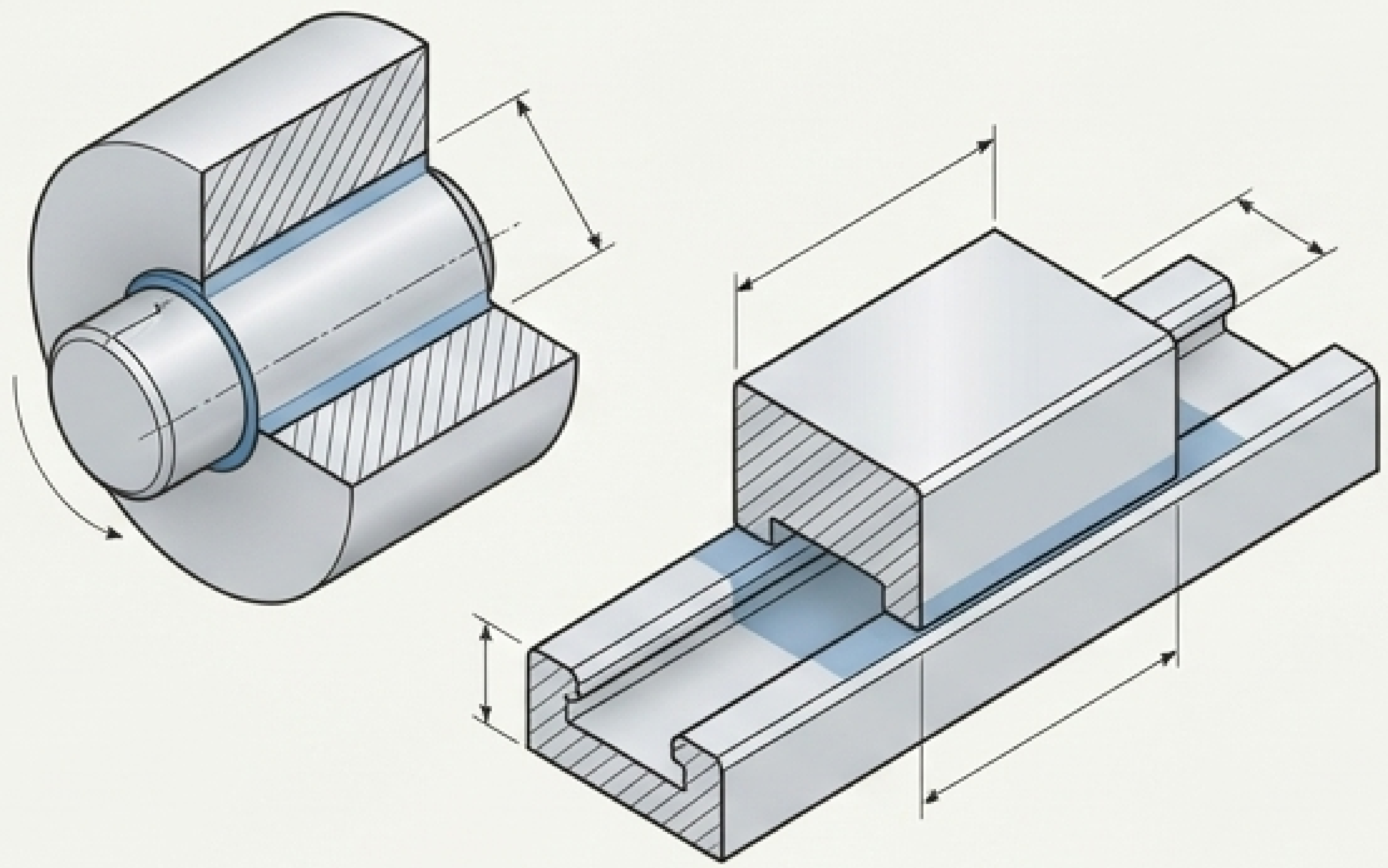
The Second Building Block: The Joint (or Kinematic Pair)

- A **Joint** (or Kinematic Pair) is a connection between two or more links that **allows some relative motion** while constraining others.
- Joints are what *remove* degrees of freedom to create a predictable system.
- **Connectivity (or Degrees of Freedom of a joint):** The number of independent parameters required to define the relative position of one link with respect to another.

If links are the bones, joints are the articulations. A door hinge is a joint: it allows rotation about one axis (1 DOF) but prevents all other motions (up/down, in/out, etc.).

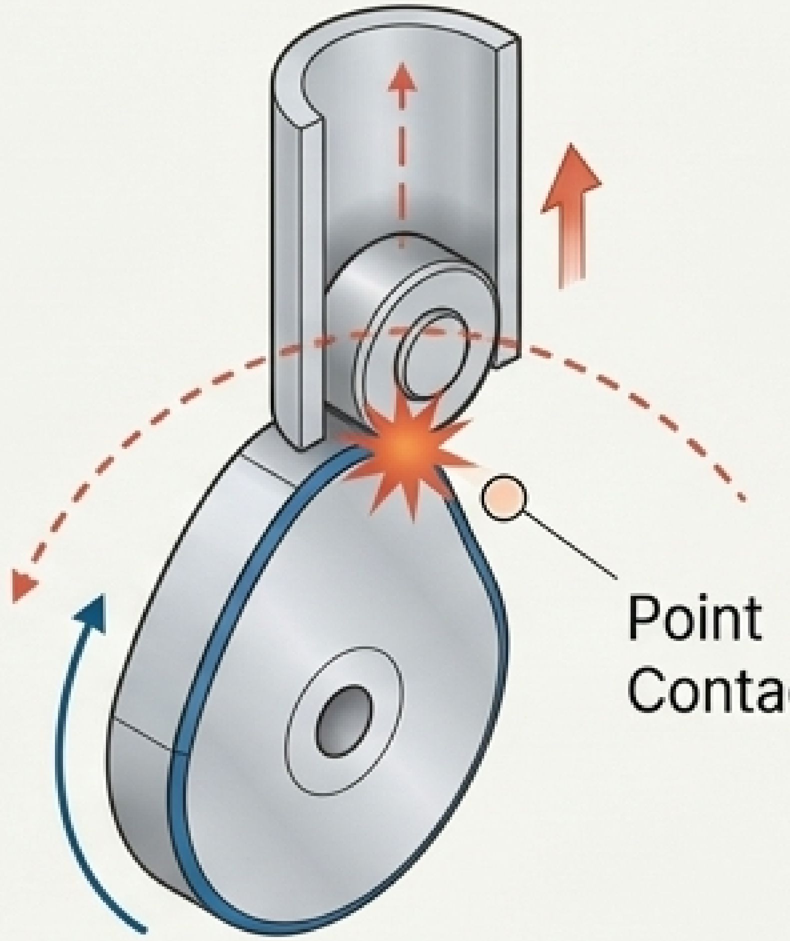
Two Families of Joints: How Links Make Contact

Lower Pairs: Surface Contact



Low contact stress, good for lubrication, robust. Formed by contact over geometrically congruent surfaces.

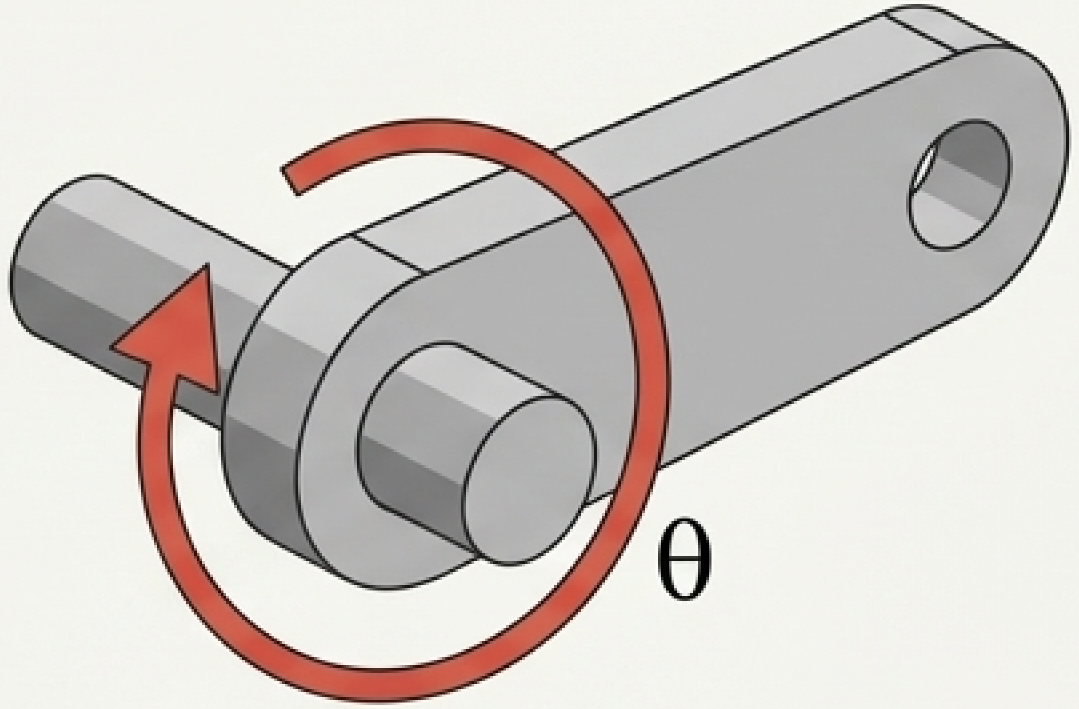
Higher Pairs: Point or Line Contact



High contact stress, allows for complex motion profiles.

We classify all joints into **two families.** Lower pairs (surface contact) are the workhorses. Higher pairs (point/line contact) allow for more complex motion but concentrate stress.

The Fundamental Planar Joints: Revolute & Prismatic

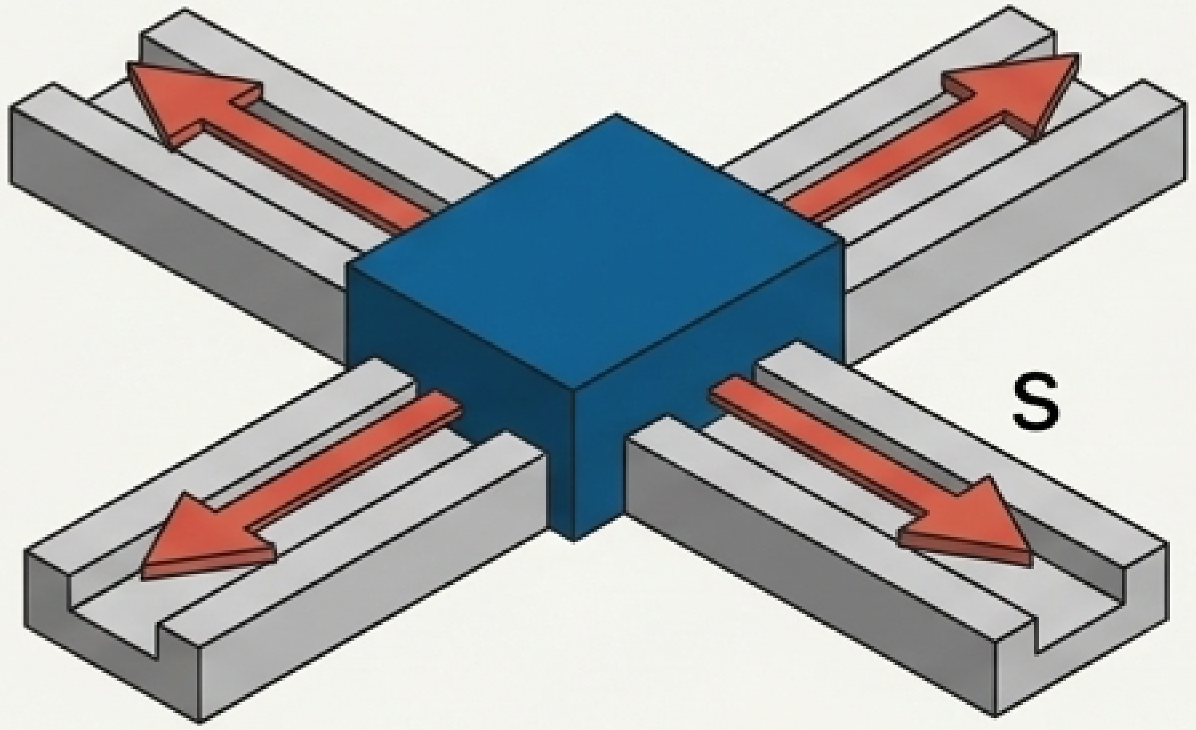


Revolute (R) Joint

Also known as a Hinge, Pin, or Turning Pair.

Allows pure **rotation**.

1 Degree of Freedom (DOF).



Prismatic (P) Joint

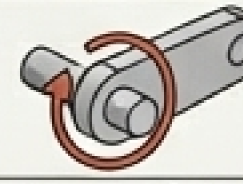
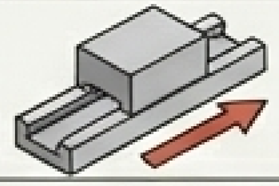
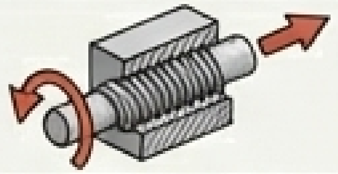
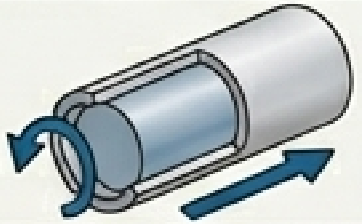
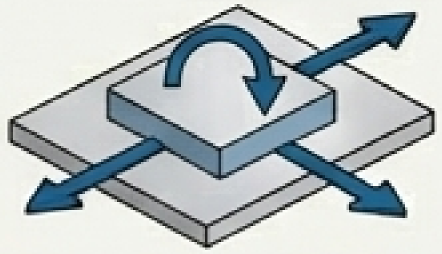
Also known as a Slider or Sliding Pair.

Allows pure linear **translation**.

1 Degree of Freedom (DOF).

For most of what we'll study initially, these two lower pairs are the most important. Virtually all the planar linkages you see are built from combinations of just these two joint types.

The Six Fundamental Lower Pair Joints

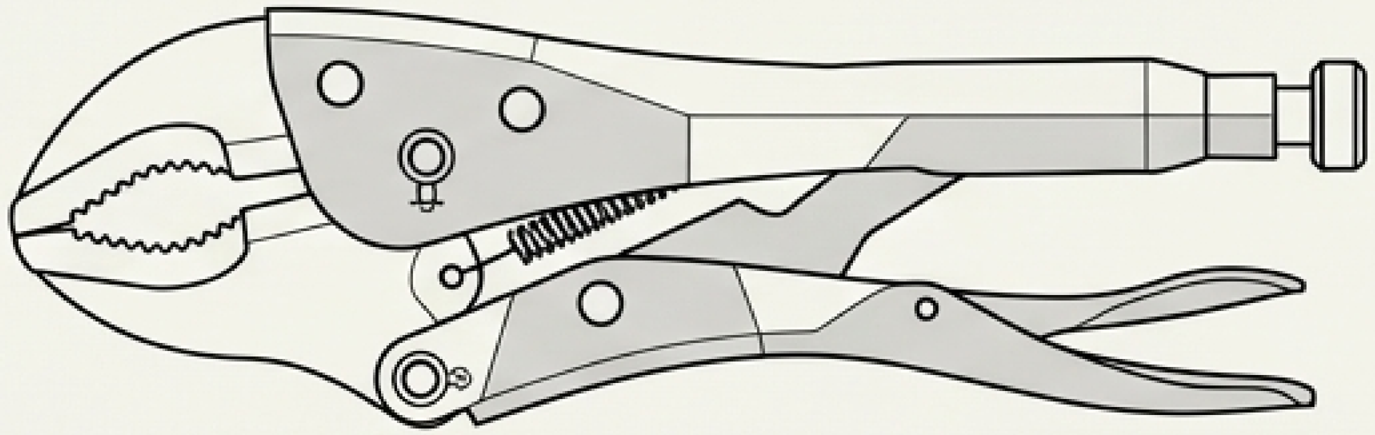
Joint Name	Degrees of Freedom (DOF)	Visual Representation
Revolute (**R**)	1-DOF (**Rotation**)	
Prismatic (**P**)	1-DOF (**Translation**)	
Helical/Screw (**H**)	1-DOF (**Coupled Rotation/Translation**)	
Cylindric (**C**)	2-DOF (**Independent Rotation/Translation**)	
Spherical/Ball (**S**)	3-DOF (**Three Rotations**)	
Planar (**PL**)	3-DOF (**Two Translations, One Rotation**)	

Expanding our view to 3D, there are only six fundamental types of lower pair joints. Every complex connection can be broken down into these. Notice how DOF increases as the joint allows more complex relative motion.

From Physical Reality to Abstract Schematic

Reality Neue Haas Grotesk

Schematic Neue Haas Grotesk



Why use schematics?

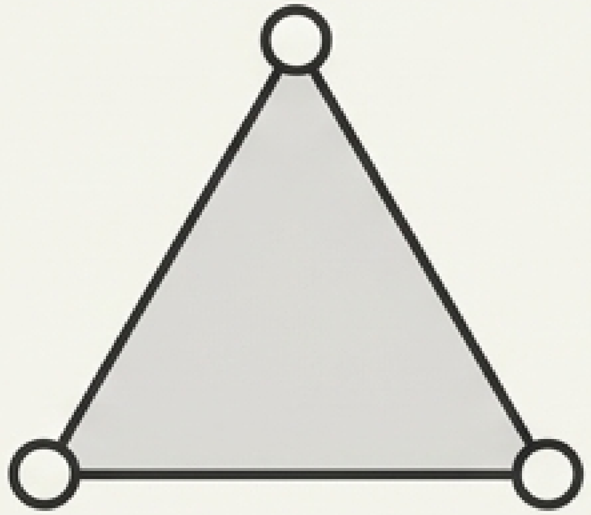
- To focus purely on **kinematics** (the geometry of motion).
- We ignore non-essential details like shape, mass, and color.
- **Links** become lines or shaded polygons.
- **Joints** become simple symbols.

As engineers, we need a universal language to describe mechanisms. Kinematic diagrams strip away all the noise and let us focus on what matters for kinematics: the links, the joints, and their dimensions.

Decoding the Blueprint of Motion

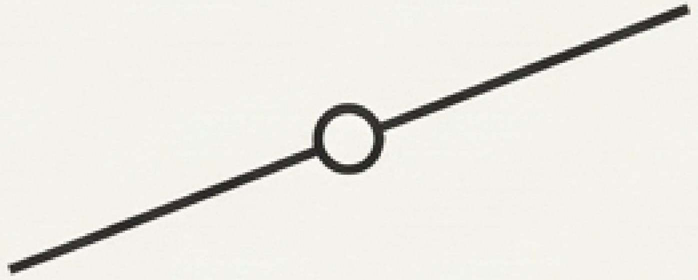
LINKS

Represents a **binary link** (connects two joints).



Represents a **ternary link** (3 joints) or **quaternary link** (4 joints). Shading is crucial to distinguish from a loop of binary links.

JOINTS



Represents a moving **revolute joint** (pin).

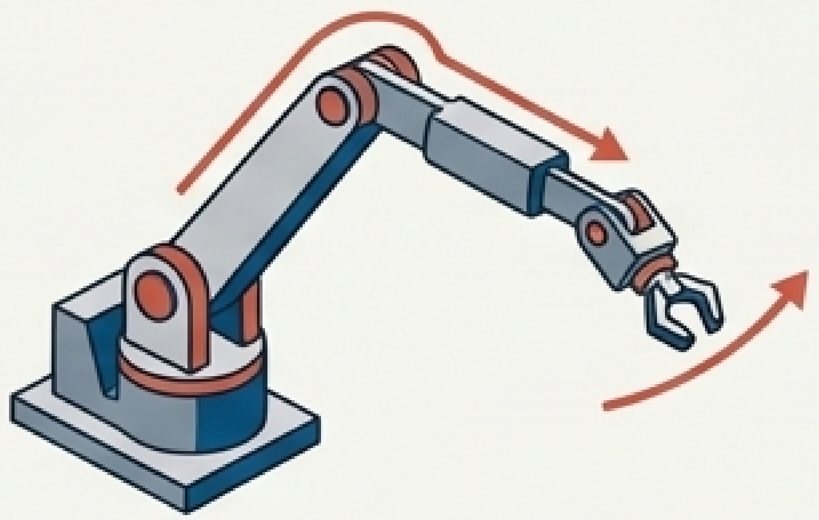
Represents a **prismatic joint** (slider).

Represents a **fixed** or 'grounded' joint. The ground link itself is considered the page or frame.

Learning to read these diagrams is like learning the alphabet. This is the symbolic language we will use for the rest of the course to analyze and design mechanisms.

Putting It All Together: Kinematic Chains

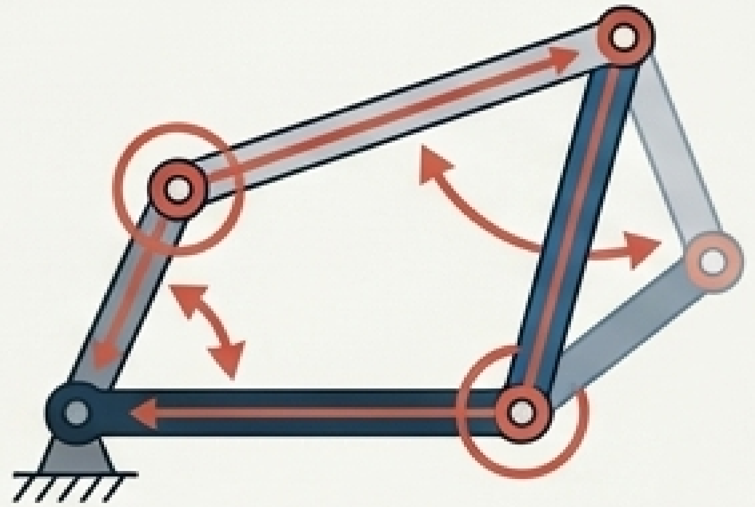
Open Chain



Links connected sequentially. Motion at one end creates a predictable motion at the other.

e.g., Excavator booms, robotic arms.

Closed Chain



Links form one or more closed loops, constraining the motion of the entire system.

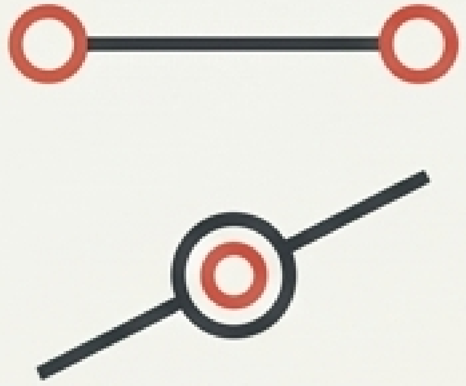
e.g., Vehicle suspensions, engine mechanisms.

Kinematic Chain: An assembly of links and joints.

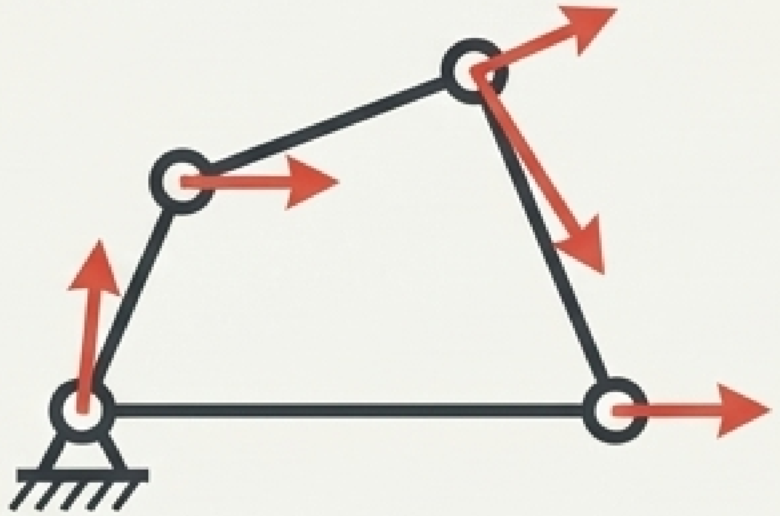
When we assemble links and joints, we create **kinematic chains**. We will spend significant time on **closed-chain four-bar linkages** as they are the simplest and most versatile building block for complex machines.

Your Journey as a Mechanism Designer

Stage 1:
Understand the Building Blocks
(Today's Lecture)



Stage 2
Kinematic Analysis
(Coming Next)



Given a mechanism, how does it move?

Stage 3
Kinematic Synthesis
(The Ultimate Goal)

Given a desired motion, what mechanism will create it?

Today, we've learned to identify the parts. Next, we will learn **Analysis** – predicting the motion of any point on a given mechanism. But the ultimate skill is **Synthesis** – starting with a problem and creating a new mechanism from scratch to solve it. That is the goal of this course.

Key Concepts Recap

- **Mechanism:** The skeleton of a machine, designed to guide motion.
- **Links:** The rigid "bones" of the mechanism (Binary, Ternary, etc.).
- **Joints:** The connections that constrain relative motion (e.g., Revolute, Prismatic). They are classified as Lower (surface contact) or Higher (point/line contact) Pairs.
- **Kinematic Diagrams:** Our abstract engineering language for analyzing motion.

For Next Class:

Read Chapter 1, Sections 1.1 - 1.6 in the textbook.

Start Seeing the World Like a Designer:

Find at least two mechanisms in your daily life (e.g., scissors, desk lamp, casement window). Try to identify the links and joints, and sketch their kinematic diagrams. We'll discuss your findings at the start of the next class.

Questions?