Mobile Robot

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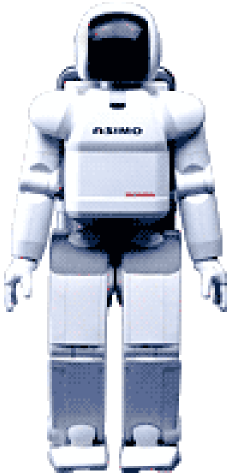
Robotics

Locomotion



- **Locomotion** is the process of causing an autonomous robot to move
  - In order to produce motion, forces must be applied to the vehicle

Wheeled Mobile Robots (WMR)

Yamabico

MagellanPro

Sojourner

ATRV-2

Hilare 2-Bis

Koy

Robotics

Wheeled Mobile Robots

- **Combination of various physical (hardware) and computational (software) components**

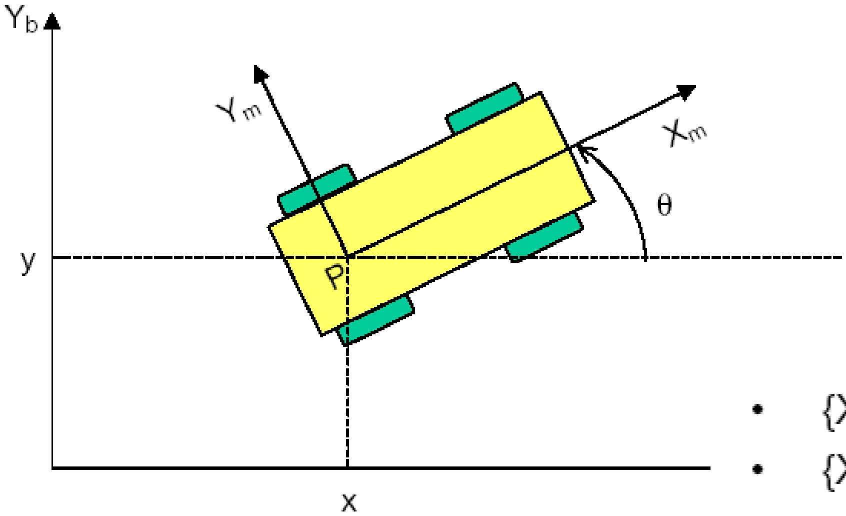
- **A collection of subsystems:**
  - **Sensing:** how the robot measures properties of itself and its environment
  - **Locomotion:** how the robot moves through its environment
  - **Control:** how the robot generate physical actions
  - **Reasoning:** how the robot maps measurements into actions
  - **Communication:** how the robots communicate with each other or with an outside operator

Robotics

Wheeled Mobile Robots

- **Locomotion —** the process of causing an robot to move.
  - In order to produce motion, forces must be applied to the robot
  - Motor output, payload
- **Kinematics** – study of the mathematics of motion without considering the forces that affect the motion.
  - Deals with the geometric relationships that govern the system
  - Deals with the relationship between control parameters and the behavior of a system.
- **Dynamics** – study of motion in which these forces are modeled
  - Deals with the relationship between force and motions.

Notation



Posture: position(x, y) and orientation θ

- $\{X_m, Y_m\}$ – moving frame
- $\{X_b, Y_b\}$ – base frame

$$q = \begin{bmatrix} x \\ y \\ \theta \end{bmatrix}$$

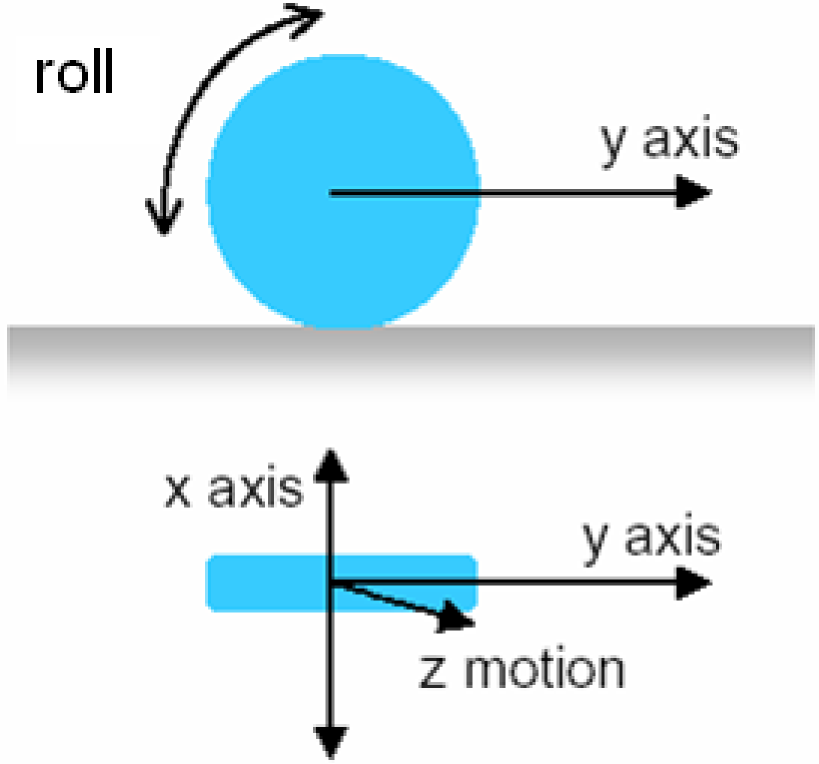
robot posture in base frame

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

Rotation matrix expressing the orientation of the base frame with respect to the moving frame

Robotics

Wheels

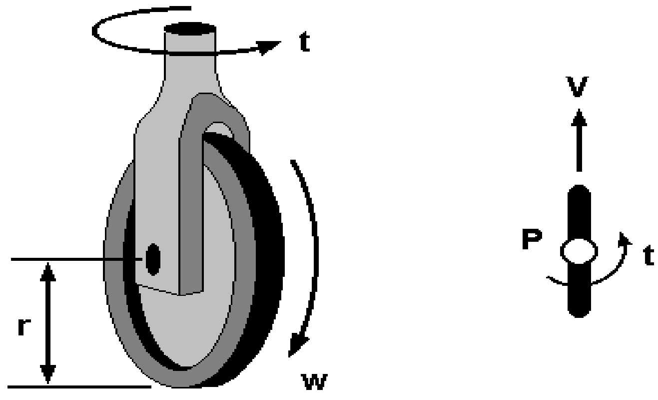


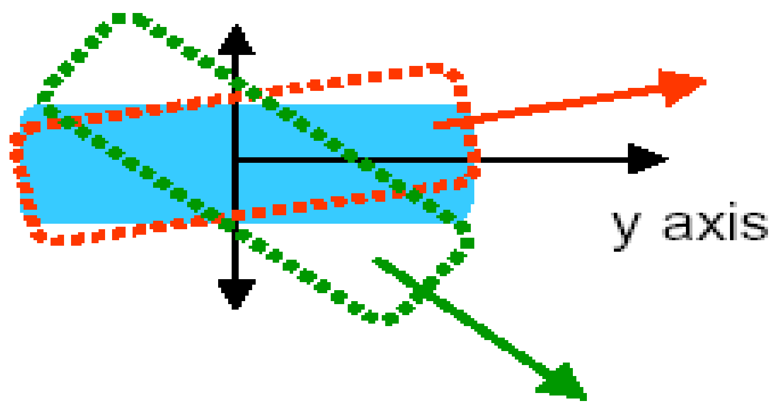
Rolling motion

Lateral slip

Steered Wheel

- **Steered wheel**
  - The orientation of the rotation axis can be controlled





Robotics

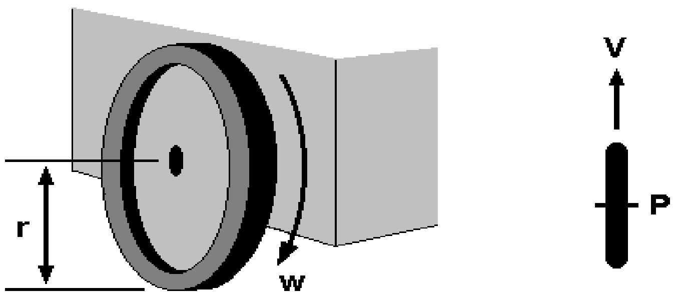
Robot wheel parameters

- For low velocities, rolling is a reasonable wheel model.
  - This is the model that will be considered in the kinematics models of WMR
- Wheel parameters:
  - r = wheel radius
  - v = wheel linear velocity
  - w = wheel angular velocity
  - t = steering velocity

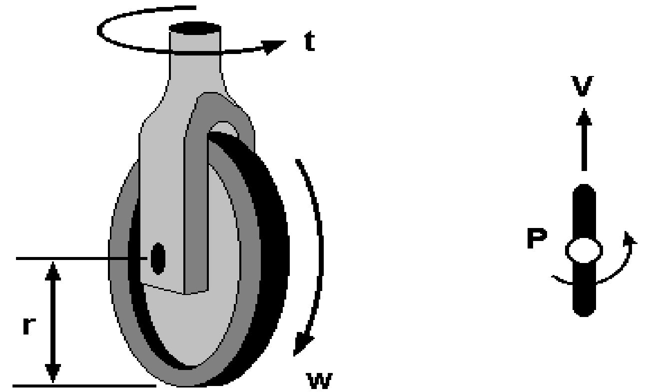
Robotics

Wheel Types

Fixed wheel

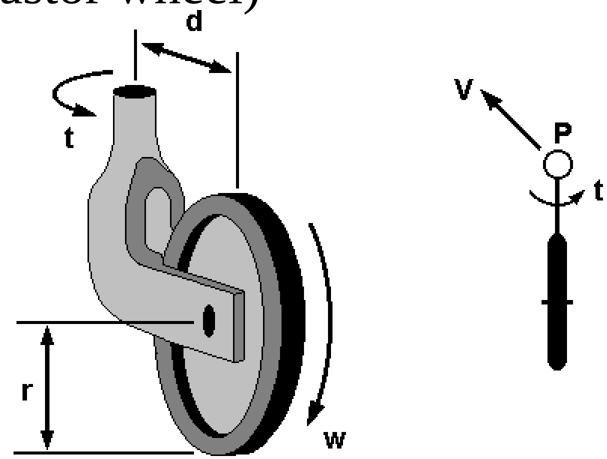


Centered orientable wheel

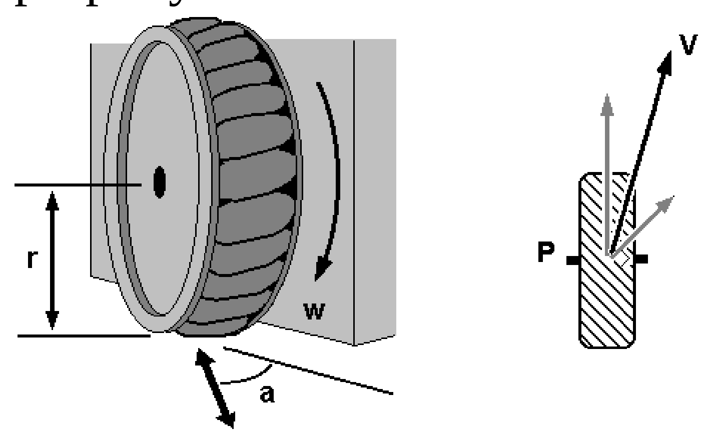


Off-centered orientable wheel

(Castor wheel)

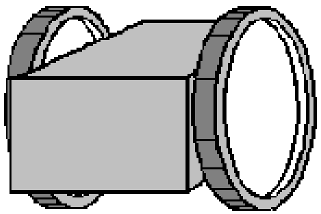


Swedish wheel: omnidirectional property



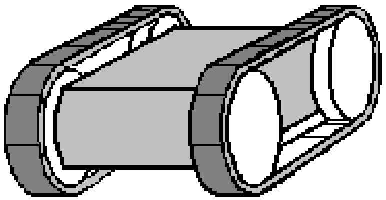
Examples of WMR

Example



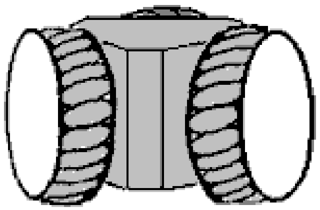
Bi-wheel type robot

- Smooth motion
- Risk of slipping
- Some times use roller-ball to make balance



Caterpillar type robot

- Exact straight motion
- Robust to slipping
- Inexact modeling of turning



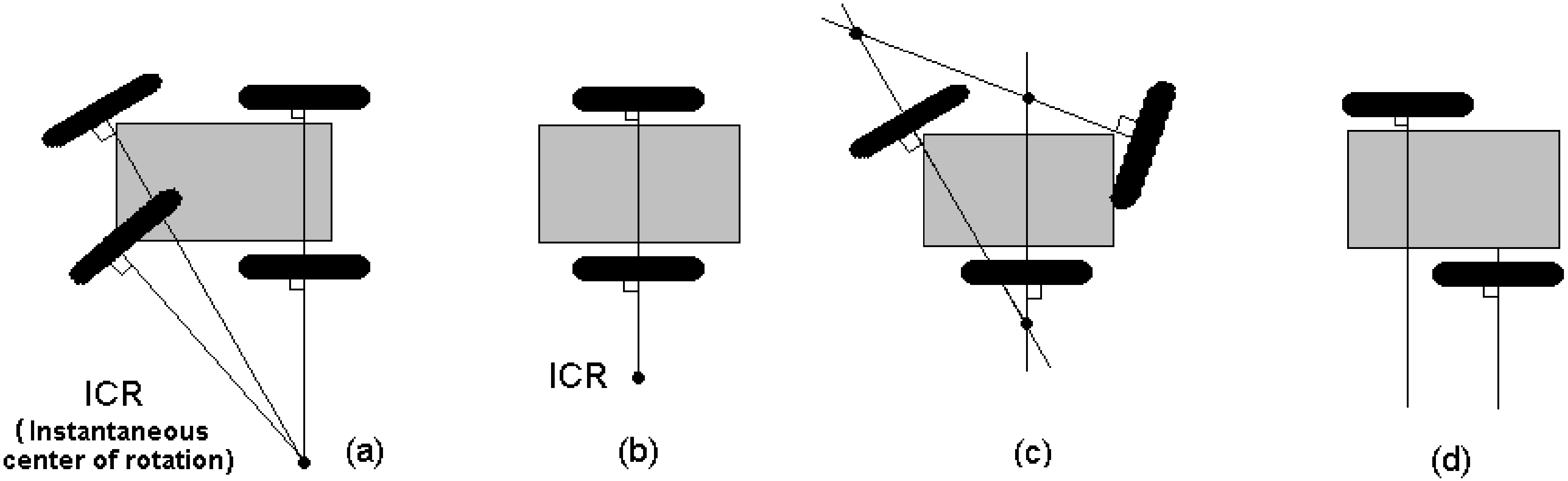
Omnidirectional robot

- Free motion
- Complex structure
- Weakness of the frame

Robotics

Mobile Robot Locomotion

- Instantaneous center of rotation (ICR) or Instantaneous center of curvature (ICC)
  - A cross point of all axes of the wheels

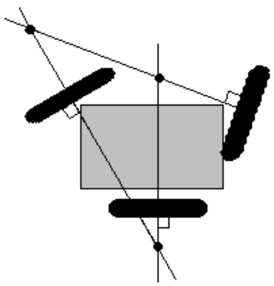


Robotics

Degree of Mobility

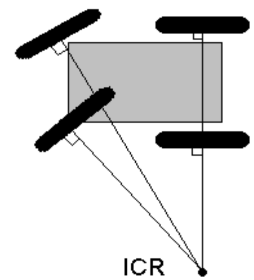
- **Degree of mobility**

  The degree of freedom of the robot motion



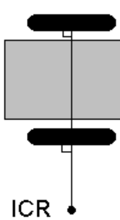
Cannot move anywhere (No ICR)

- Degree of mobility : 0



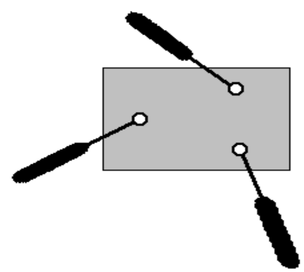
Fixed arc motion (Only one ICR)

- Degree of mobility : 1



Variable arc motion (line of ICRs)

- Degree of mobility : 2



Fully free motion

(ICR can be located at any position)

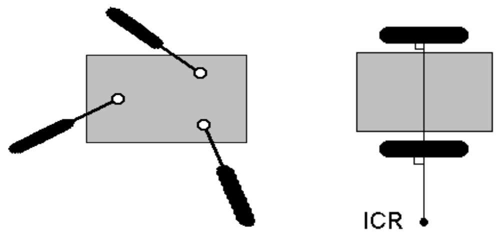
- Degree of mobility : 3

Robotics

Degree of Steerability

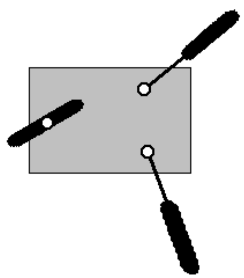
- **Degree of steerability**

The number of centered orientable wheels that can be steered independently in order to steer the robot

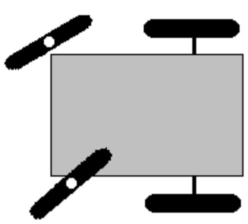


No centered orientable wheels

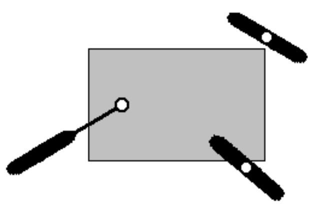
- Degree of steerability : 0



One centered orientable wheel



Two mutually dependent centered orientable wheels



Two mutually independent centered orientable wheels

- Degree of steerability : 1
- Degree of steerability : 2

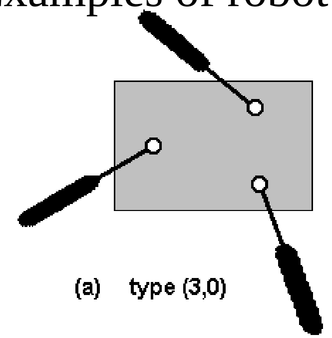
Degree of Maneuverability

- The overall degrees of freedom that a robot can manipulate:

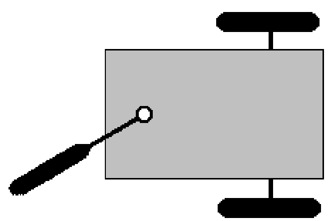
$$\delta_M = \delta_m + \delta_s$$

Degree of Mobility	3	2	2	1	1
Degree of Steerability	0	0	1	1	2

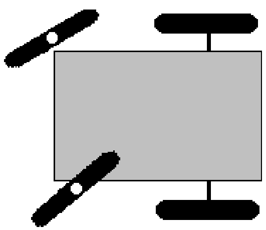
- Examples of robot types (degree of mobility, degree of steerability)



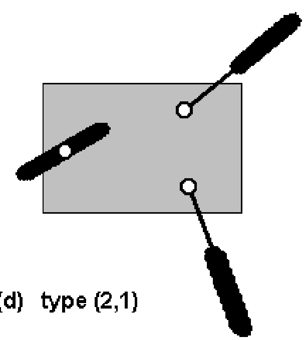
(a) type (3,0)



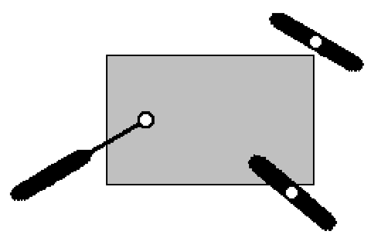
(b) type (2,0)



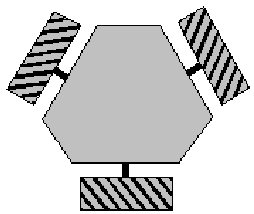
(c) type (1,1)



(d) type (2,1)



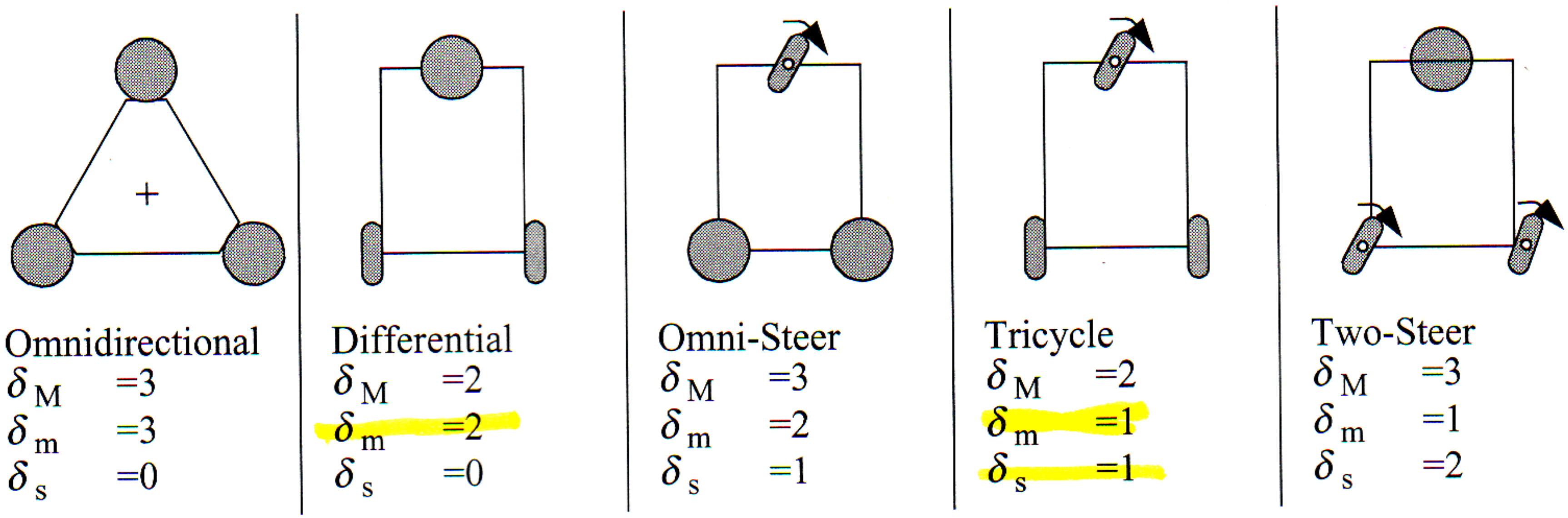
(e) type (1,2)



(f) type (3,0)

Degree of Maneuverability

$$\delta_M = \delta_m + \delta_s$$



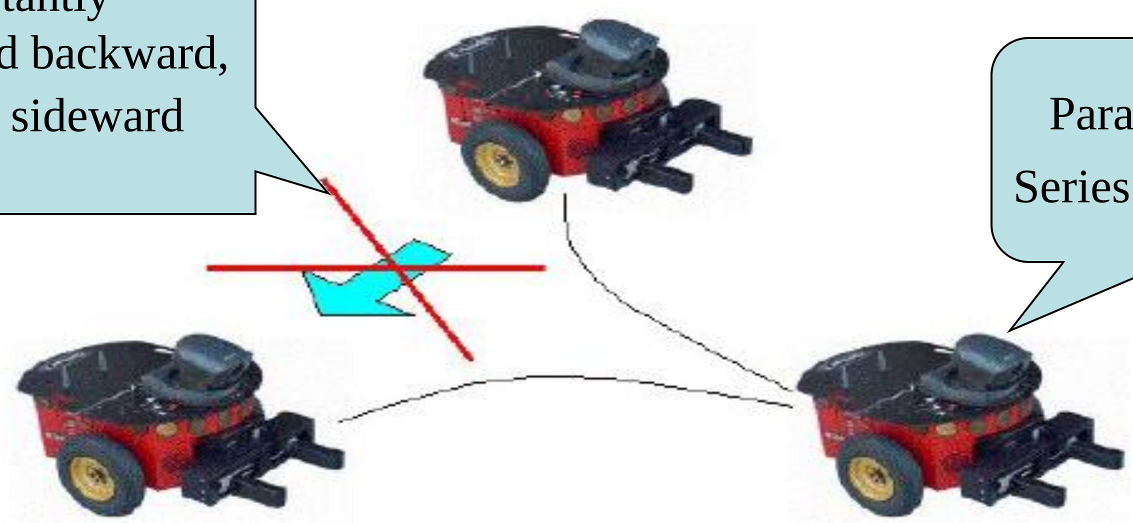
Non-holonomic constraint

A non-holonomic constraint is a constraint on the feasible **velocities** of a body

So what does that mean?

Your robot can move in some directions (forward and backward), but not others (sideward).

The robot can instantly move forward and backward, but can not move sideward



Parallel parking,

Series of maneuvers

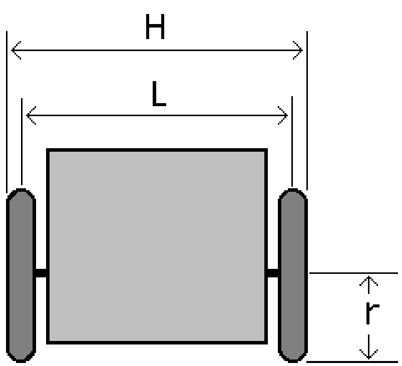
Robotics

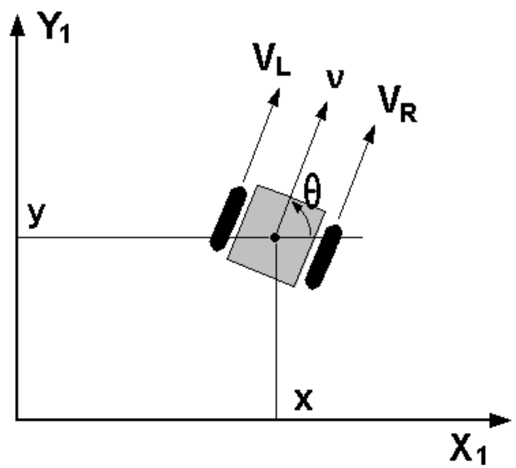
Types of driving (steering)

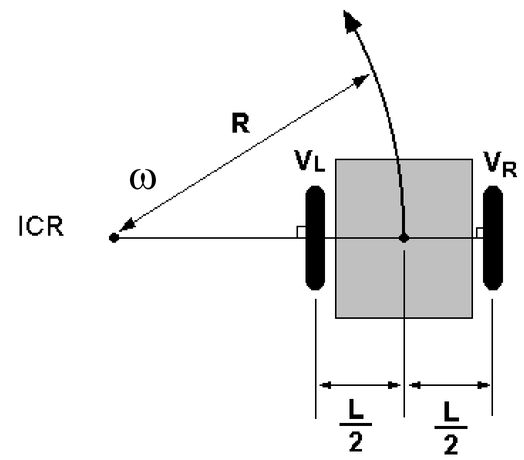
1. Differential Drive
   - two driving wheels (plus roller-ball for balance)
   - simplest drive mechanism
   - sensitive to the relative velocity of the two wheels (small error result in different trajectories, not just speed)
2. Steered wheels (tricycle, bicycles, wagon)
   - Steering wheel + rear wheels
   - cannot turn $\pm 90^{\circ}$
   - limited radius of curvature
3. Synchronous Drive
4. Omni-directional
5. **Car Drive (Ackerman Steering)**

Robotics

1-Differential Drive







- Posture of the robot

$$P = \begin{pmatrix} x \\ y \\ \theta \end{pmatrix}$$

(x,y) : Position of the robot

θ : Orientation of the robot

- Control input

$$U = \begin{pmatrix} v \\ w \end{pmatrix}$$

v : Linear velocity of the **robot**

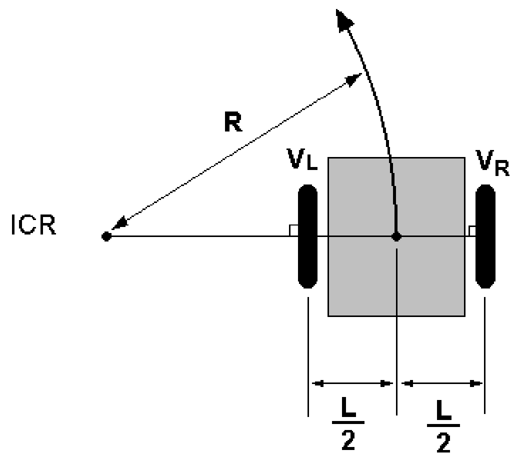
w : Angular velocity of the **robot**

(notice: not for each wheel)

Robotics

Motion Control

- Instantaneous center of rotation



$$(V_R - V_L)/\ L = V_R\ /(R + \frac{L}{2})$$

$$R = \frac{L}{2}\frac{V_R + V_L}{V_R - V_L}$$

R : Radius of rotation

- Straight motion

  R = Infinity → $V_R = V_L$

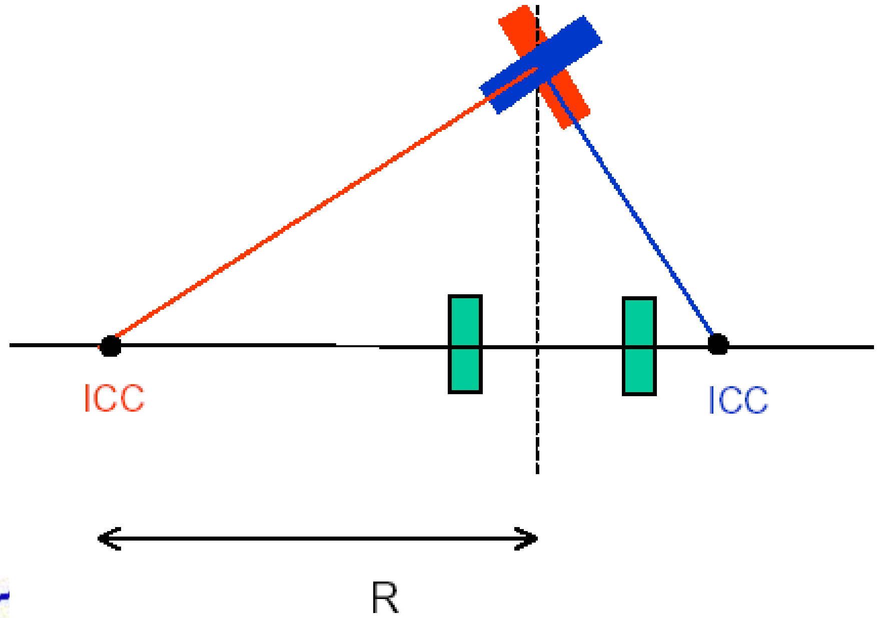
- Rotational motion

  R = 0 → $V_R = -V_L$

Robotics

2- Tricycle

- Three wheels and odometers on the two rear wheels
- Steering and power are provided through the front wheel
- control variables:
  – steering direction α(t)
  – angular velocity of steering wheel $w_s(t)$



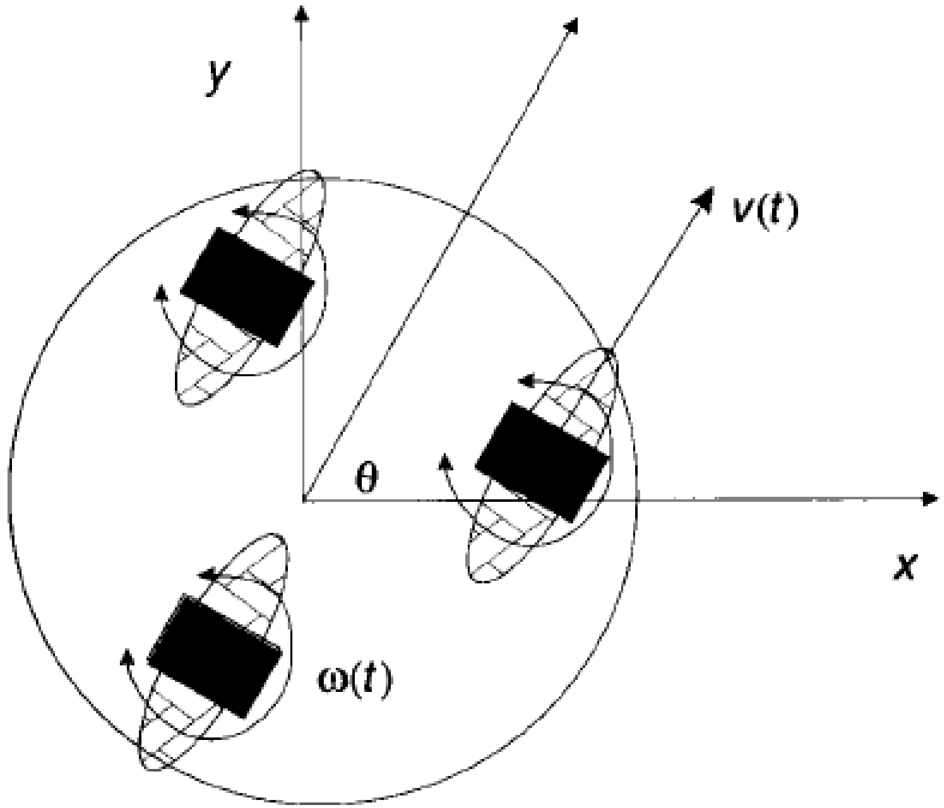
The ICC must lie on the line that passes through, and is perpendicular to, the fixed rear wheels

3-Synchronous Drive

- In a synchronous drive robot (synchronous drive) each wheel is capable of being driven and steered.
- Typical configurations
  - Three steered wheels arranged as vertices of an equilateral
  - triangle often surmounted by a cylindrical platform
  - All the wheels turn and drive in unison
- This leads to a holonomic behavior

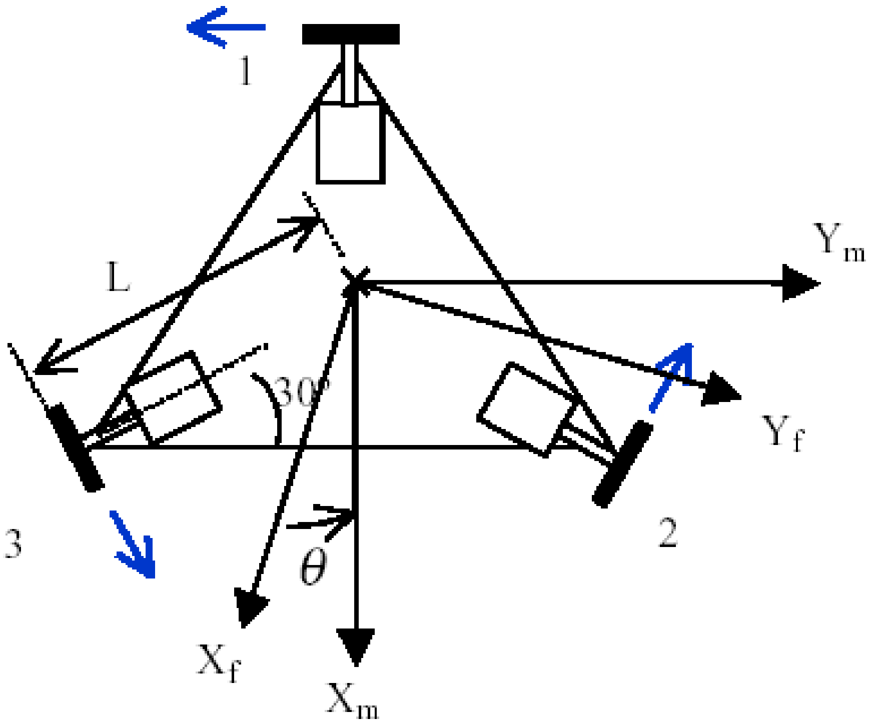
Robotics

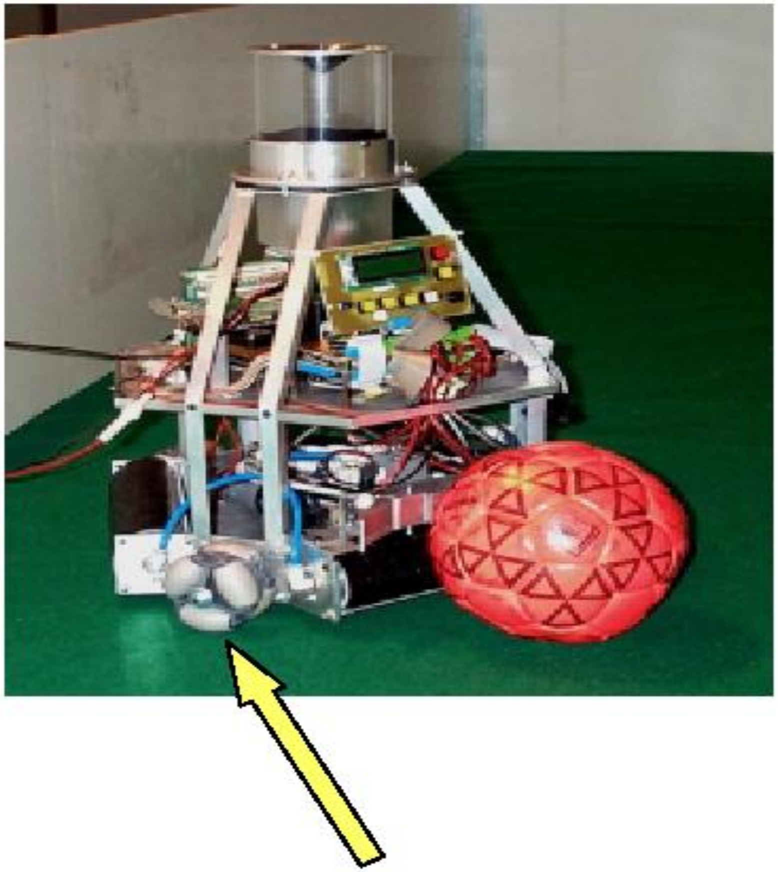
Synchronous Drive



Robotics

4-Omidirectional

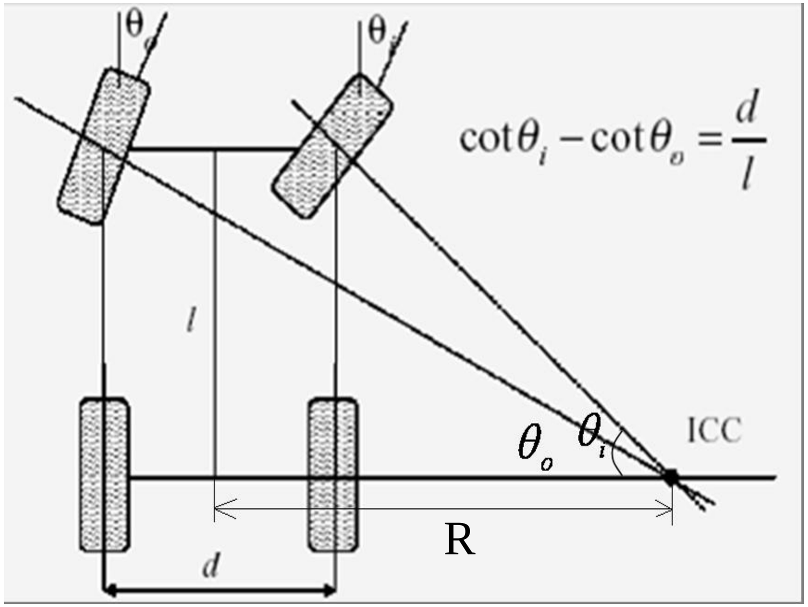




Swedish Wheel

Robotics

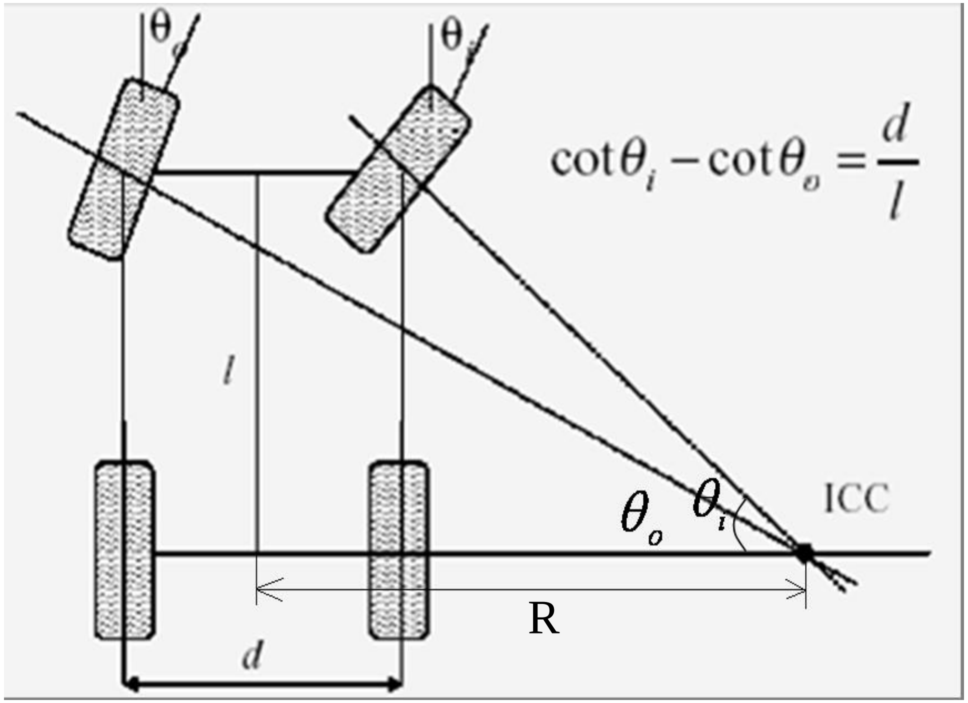
5-Car Drive (Ackerman Steering)



- Used in motor vehicles, the inside front wheel is rotated slightly sharper than the outside wheel (reduces tire slippage).
- Generally the method of choice for outdoor autonomous vehicles.

Robotics

Ackerman Steering



where

d = lateral wheel separation

l = longitudinal wheel separation

θi = relative steering angle of inside wheel

θo = relative steering angle of outside wheel

R=distance between ICC to centerline of the vehicle

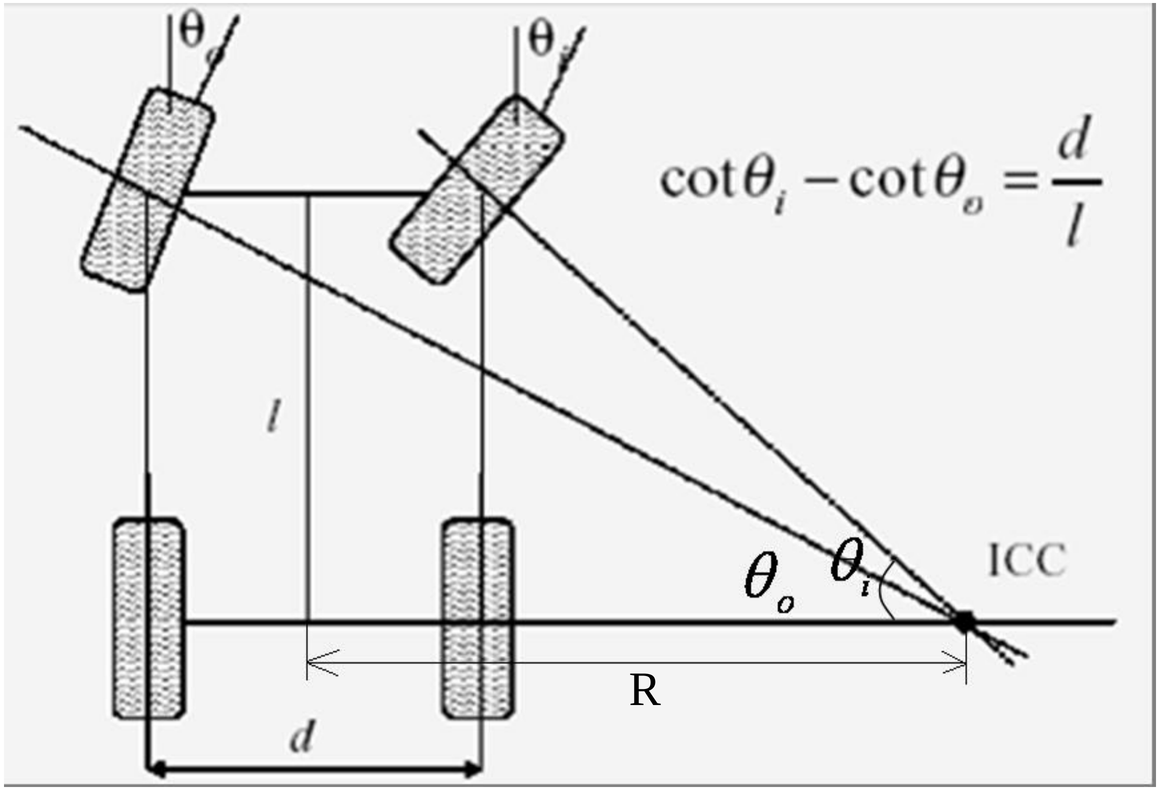
Robotics

Ackerman Steering

- The Ackerman Steering equation:
  - :

$$\cot\theta_i - \cot\theta_o = \frac{d}{l}$$

$$\cot\theta = \frac{\cos\theta}{\sin\theta}$$



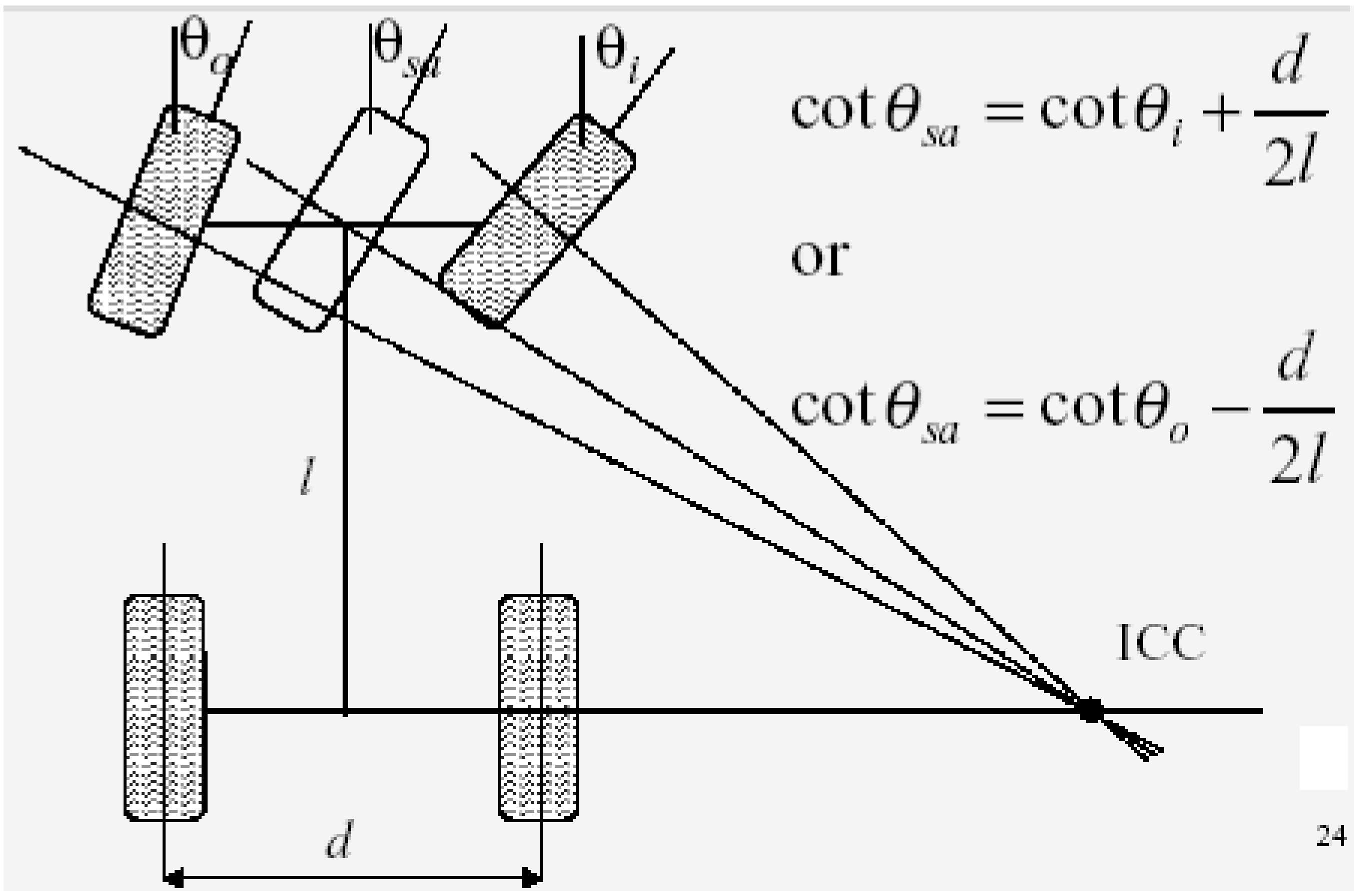
$$\cot\theta_i - \cot\theta_o$$

$$= \frac{R - d/2}{l} - \frac{R + d/2}{l}$$

$$= \frac{d}{l}$$

Ackerman Steering

Equivalent:



Summary

- Mobile Robot
- Classification of wheels
  - Fixed , Centered , Off-centered , Swedish wheel
- Degree of Maneuverability
  - Degrees of mobility+ Degree of steerability
- 5 types of driving (steering) methods
  - Differential Drive
  - Steered wheels (tricycle, bicycles, wagon)
  - Synchronous Drive
  - Omni-directional
  - Car Drive (Ackerman Steering)

Robotics

Thank you!

Robotics