Hochschule
Bonn-Rhein-Sieg
University of Applied Sciences

b-it Bonn-Aachen International Center for Information Technology

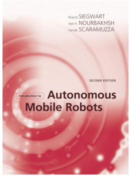
Institute for AI and Autonomous Systems

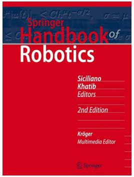
Locomotion

A General Overview

Dr. Alex Mitrevski
Master of Autonomous Systems

Structure





- Locomotion mechanisms
- Wheels and drives

Locomotion Mechanisms

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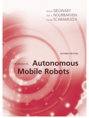
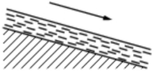
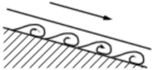
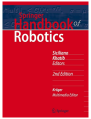
Locomotion is "the action or power of a human, animal, cell, etc., of moving from one place or position to another unaided; progressive movement of the whole" (Oxford Dictionary)

Locomotion in Natural Systems



Type of motion	Resistance to motion	Basic kinematics of motion
Flow in a Channel 	Hydrodynamic forces	Eddies 
Crawl 	Friction forces	 Longitudinal vibration
Sliding 	Friction forces	 Transverse vibration
Running 	Loss of kinetic energy	Periodic bouncing on a spring 
Walking 	Loss of kinetic energy	Rolling of a polygon (see figure 2.2) 

A Variety of Robot Locomotion Mechanisms



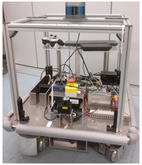


Fig. 67.22 ASIMO and artificial landmarks on the floor

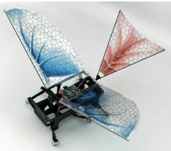
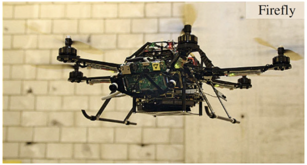


Fig. 23.12 DASH+Wings (after [23.53])



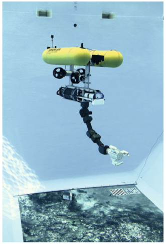


Fig. 25.9 Girona 500 I-AUV

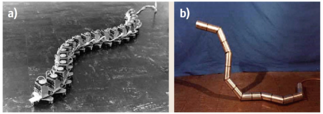
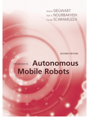


Fig. 20.1 Hirose's snake robots starting (a) with the active chord (ACM III) and (b) Oblix/Mogura mechanisms (after [20.2])

From Locomotion to Kinematics



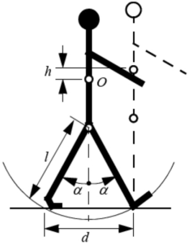


Figure 2.2
A biped walking system can be approximated by a rolling polygon, with sides equal in length *d* to the span of the step. As the step size decreases, the polygon approaches a circle or wheel with the radius *l*.

- Moving robots around is (clearly) one important objective in mobile robotics

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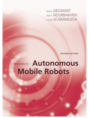

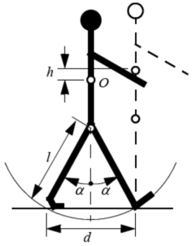

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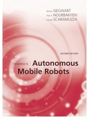

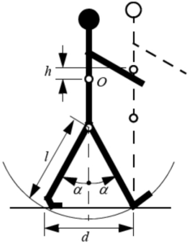

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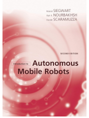
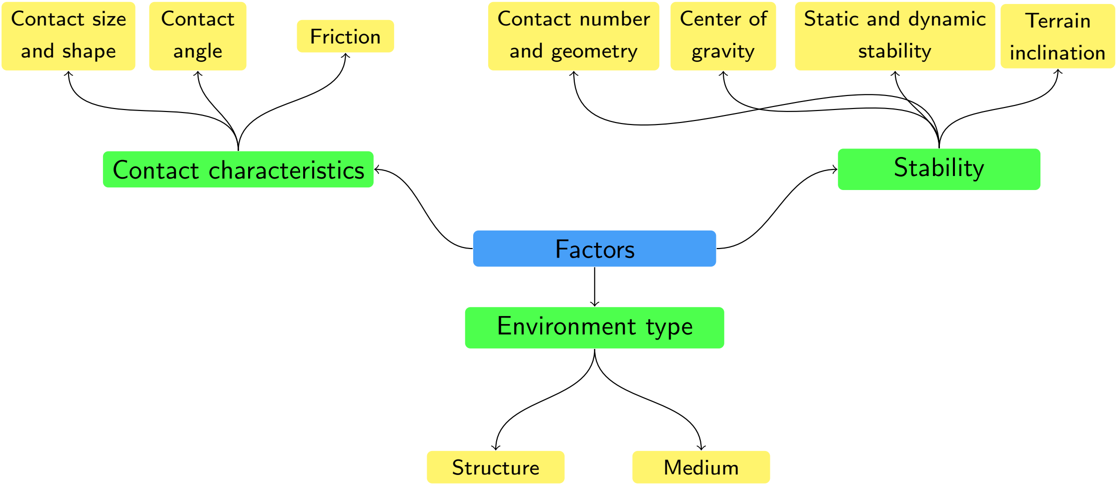
- Understanding the locomotion properties of a robot is a **prerequisite for developing mathematical models to represent motion**
- The physical representation of motion based on considerations of geometry and velocity is the problem of **kinematics**
  - We will discuss kinematics in the next lecture

Factors Affecting Locomotion





Wheel and Drive Types

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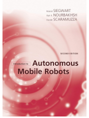
  - **The control of wheeled robots is considerably simpler** than for other mechanisms
- In the rest of this lecture, we will look at the main wheel types and various mobile structures resulting from those

Wheel Types



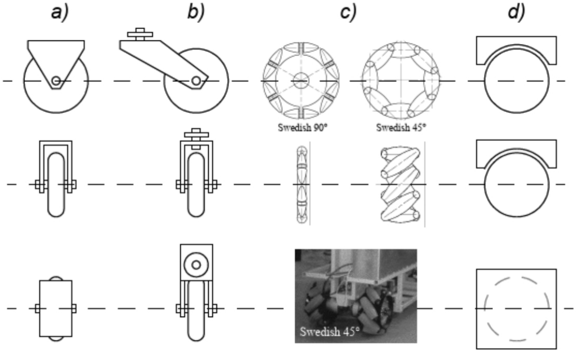
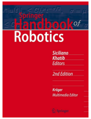
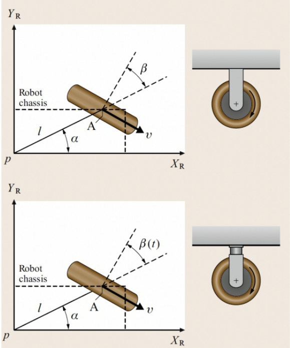


Figure 2.25
The four basic wheel types. (a) Standard wheel: two degrees of freedom; rotation around the (motorized) wheel axle and the contact point.(b) castor wheel: two degrees of freedom; rotation around an offset steering joint. (c) Swedish wheel: three degrees of freedom; rotation around the (motorized) wheel axle, around the rollers, and around the contact point. (d) Ball or spherical wheel: realization technically difficult.

Standard Wheel





Geometry of a standard wheel. (above) Passive fixed wheel. (below) Active orientable wheel.

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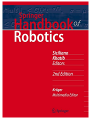
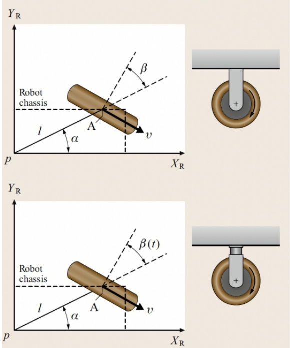
Standard Wheel





Geometry of a standard wheel. (above) Passive fixed wheel. (below) Active orientable wheel.

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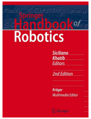

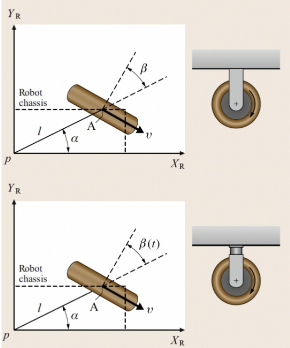

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- On a robot base, standard wheels can be **active steerable** (with adjustable $\boldsymbol{v}$ and β) or **passive** (with a fixed β and $\boldsymbol{v}$ determined based on the motion of the other wheels on the base)
  - On a car, the front two wheels are active, while the back two wheels are passive

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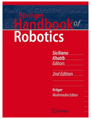

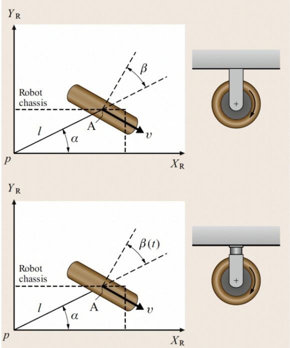

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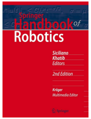
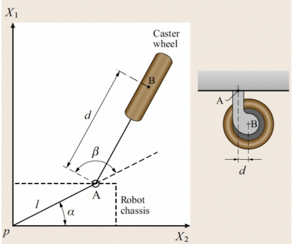
- A standard wheel introduces a **non-holonomic motion constraint** (sideways motion is not possible)

Caster Wheel





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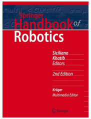
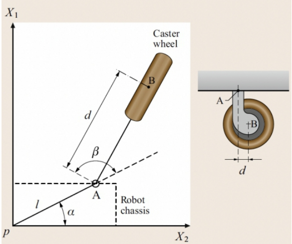
Caster Wheel





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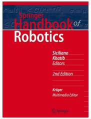

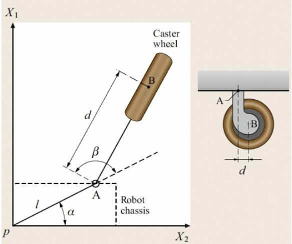

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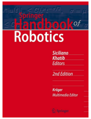

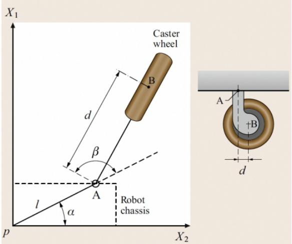

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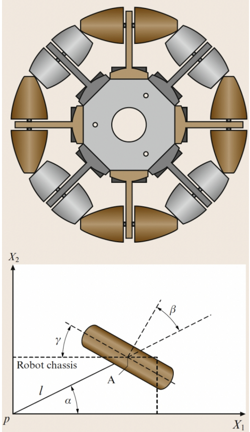
- If the driving and steering velocities of a caster wheel are controlled independently, **holonomic motion** can be achieved
  - Appropriate driving and steering velocities can be found for a desired velocity at point A

Swedish Wheel



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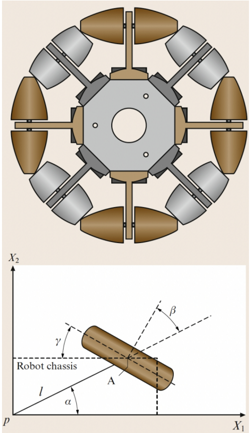

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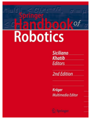

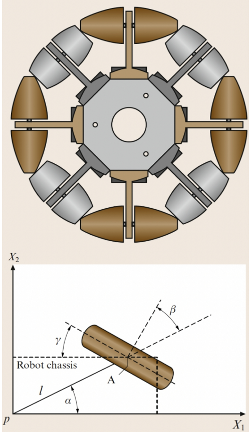

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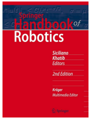
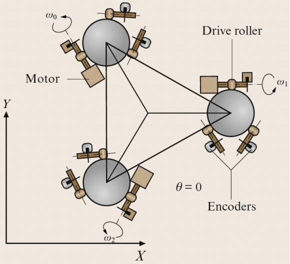
- In a Swedish wheel, **only the driving velocity is controllable**, while **the rollers are able to rotate freely**
- Through the free rotation of the rollers, **a Swedish wheel can achieve lateral velocity**, enabling a robot to move holonomically
  - The YouBot platform that we have in our lab has a base consisting of four Swedish wheels

Spherical Wheel





Geometry of a spherical wheel

- A spherical wheel is constructed by **a sphere surrounded by rollers** (both active and passive)
  - the active rollers induce rotational motion of the sphere
  - the passive rollers provide constraints on the motion

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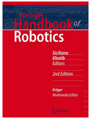

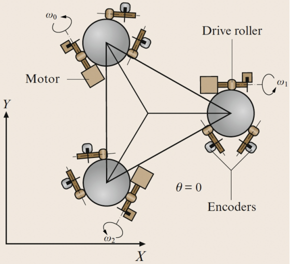

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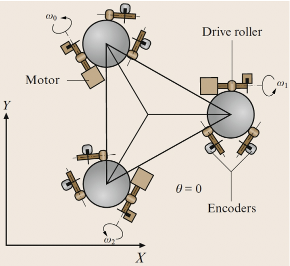

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- A spherical wheel is constructed by **a sphere surrounded by rollers** (both active and passive)
  - the active rollers induce rotational motion of the sphere
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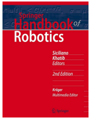
- Just as Swedish wheels, spherical wheels can move holonomically
- Spherical wheels are, however, the least frequent in practical applications due to:
  - various design challenges (spherical wheels need a precise point contact) and
  - lack of robustness to ground conditions (think of how sensitive an old, wheel-controlled mouse was to the supporting surface and even a little dirt on it)

Two-Wheeled Mobile Structures



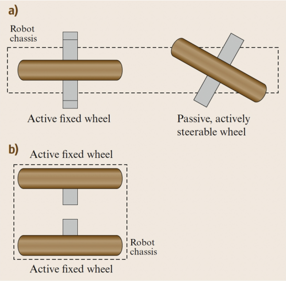
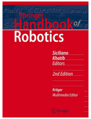


Fig. 24.6 (a) Bicycle-type robot and (b) inverted-pendulum-type robot

- A two-wheeled mobile structure is composed of **two wheels that should always be in touch with the ground**

Two-Wheeled Mobile Structures



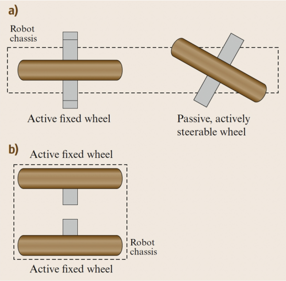


Fig. 24.6 **(a)** Bicycle-type robot and **(b)** inverted-pendulum-type robot

- A two-wheeled mobile structure is composed of **two wheels that should always be in touch with the ground**
- There are two main types of two-wheeled structures (illustrated on the left):
  - A bicycle structure (one active and one passive wheel)
  - A differential drive structure with two active fixed wheels

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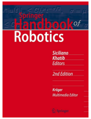

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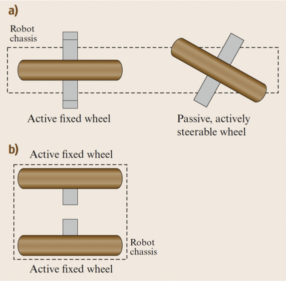

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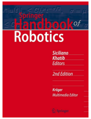

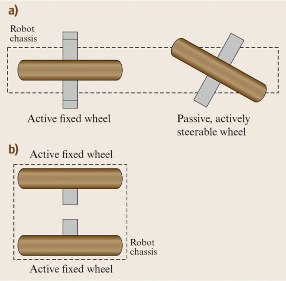

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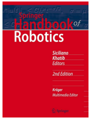
  - A differential drive structure with two active fixed wheels
- Bicycles are **dynamically stable, but statically unstable**; not very useful for robots
- For a differential drive, **balancing control is usually used for static stability** (inverted pendulum)

Mobile Structures With Three Wheels



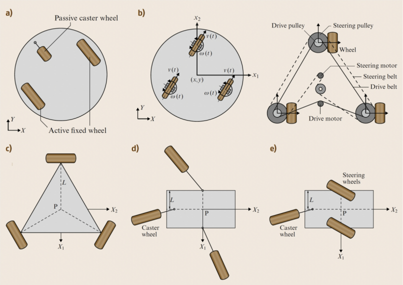
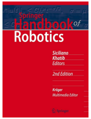


Fig. 24.7 (a) Two-wheel differential drive, (b) synchronous drive, (c) omnimobile robot with Swedish wheels, (d) omnimobile robot with active caster wheels, and (e) omnidirectional robot with active steerable wheels

- Three-wheeled structures enable more flexible combinations of wheels

Mobile Structures With Three Wheels



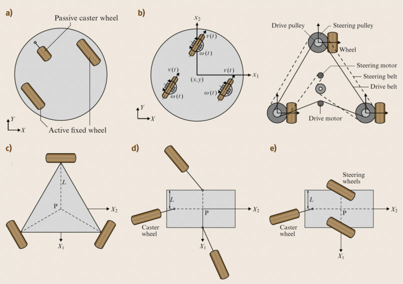
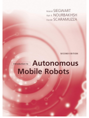
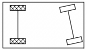
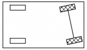
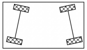
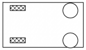
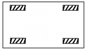
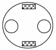
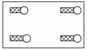


Fig. 24.7 (a) Two-wheel differential drive, (b) synchronous drive, (c) omnimobile robot with Swedish wheels, (d) omnimobile robot with active caster wheels, and (e) omnidirectional robot with active steerable wheels

- Three-wheeled structures enable more flexible combinations of wheels
- Some common three-wheeled structures are illustrated on the left
  - Note that omnidirectionality can be achieved in multiple ways, for instance three Swedish or caster wheels, but also one caster and two steerable wheels

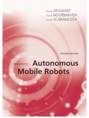
Four-Wheeled Structures

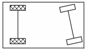
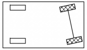
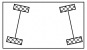
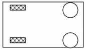
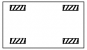
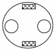
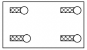


# of wheels	Arrangement	Description	Typical examples
4		Two motorized wheels in the rear, two steered wheels in the front; steering has to be different for the two wheels to avoid slipping/skidding.	Car with rear-wheel drive
		Two motorized and steered wheels in the front, two free wheels in the rear; steering has to be different for the two wheels to avoid slipping/skidding.	Car with front-wheel drive
		Four steered and motorized wheels	Four-wheel drive, four-wheel steering Hyperion (CMU)
		Two traction wheels (differential) in rear/front, two omnidirectional wheels in the front/rear	Charlie (DMT-EPFL)
		Four omnidirectional wheels	Carnegie Mellon Uranus
		Two-wheel differential drive with two additional points of contact	EPFL Khepera, Hyperbot Chip
		Four motorized and steered castor wheels	Nomad XR4000

- Four-wheeled structures **provide more stability at high speeds**

Four-Wheeled Structures



# of wheels	Arrangement	Description	Typical examples
4		Two motorized wheels in the rear, two steered wheels in the front; steering has to be different for the two wheels to avoid slipping/skidding.	Car with rear-wheel drive
		Two motorized and steered wheels in the front, two free wheels in the rear; steering has to be different for the two wheels to avoid slipping/skidding.	Car with front-wheel drive
		Four steered and motorized wheels	Four-wheel drive, four-wheel steering Hyperion (CMU)
		Two traction wheels (differential) in rear/front, two omnidirectional wheels in the front/rear	Charlie (DMT-EPFL)
		Four omnidirectional wheels	Carnegie Mellon Uranus
		Two-wheel differential drive with two additional points of contact	EPFL Khepera, Hyperbot Chip
		Four motorized and steered castor wheels	Nomad XR4000

- Four-wheeled structures **provide more stability at high speeds**
- There is a variety of structures that can be made with four wheels (some of these are described on the left)
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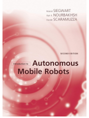
Four-Wheeled Structures



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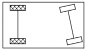
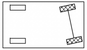
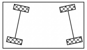
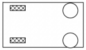
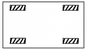
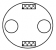
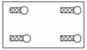
4		Two motorized wheels in the rear, two steered wheels in the front; steering has to be different for the two wheels to avoid slipping/skidding.	Car with rear-wheel drive
		Two motorized and steered wheels in the front, two free wheels in the rear; steering has to be different for the two wheels to avoid slipping/skidding.	Car with front-wheel drive
		Four steered and motorized wheels	Four-wheel drive, four-wheel steering Hyperion (CMU)
		Two traction wheels (differential) in rear/front, two omnidirectional wheels in the front/rear	Charlie (DMT-EPFL)
		Four omnidirectional wheels	Carnegie Mellon Uranus
		Two-wheel differential drive with two additional points of contact	EPFL Khepera, Hyperbot Chip
		Four motorized and steered castor wheels	Nomad XR4000

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  - Except in autonomous vehicles, car-like structures are not very common in
- With a four-wheeled mobile base, **a suspension mechanism is required** to guarantee that all four wheels have continuous ground contact

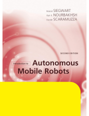
Properties of Moving Bodies

Stability

The property of a robot to remain stable while static (static stability) or during motion (dynamic stability).

- For a wheeled robot, **three wheels are typically sufficient to guarantee static stability**

Properties of Moving Bodies



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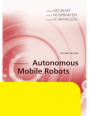
Maneuverability

Refers to the **degrees of freedom of a mobile platform that can be actively controlled**

- A maneuverability of 3 for a planar robot means that the robot is omnidirectional (its position and orientation can be controlled)
- Can be determined mathematically based on the constraints imposed by the mobile base structure

Properties of Moving Bodies



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Controllability

A property describing the simplicity of controlling the degrees of freedom of a mobile platform

- Higher maneuverability typically reduces the controllability