Mobile Robot Mechanism

Howie Choset

CLASSIFICATIONS

Field

Factory

CLASSIFICATIONS

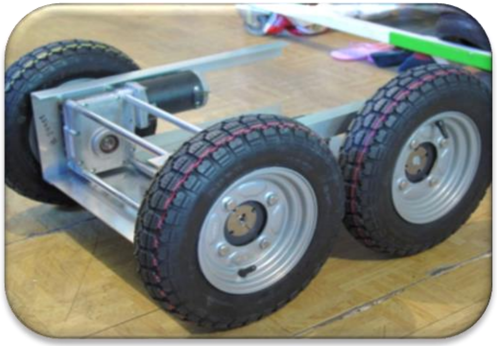
Outdoor Indoor

CLASSIFICATIONS

Wheeled

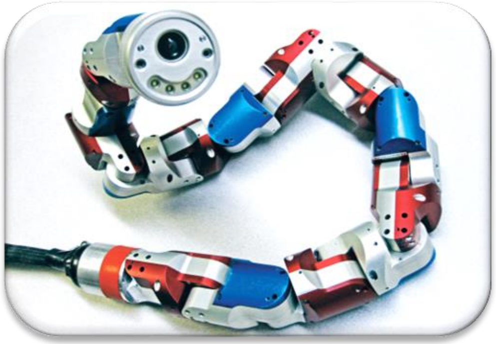
Non-Wheeled

CLASSIFICATIONS

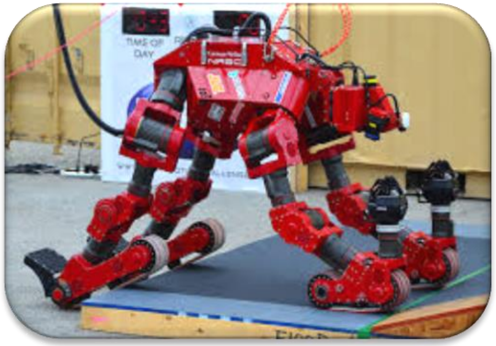


Wheeled

Legged

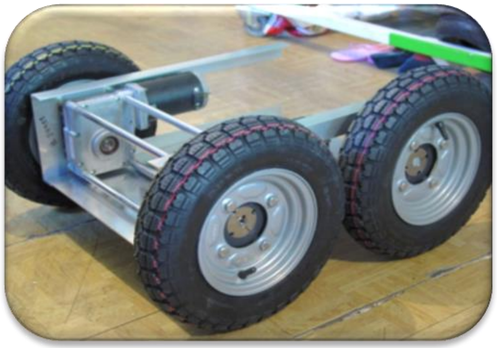


Whole body



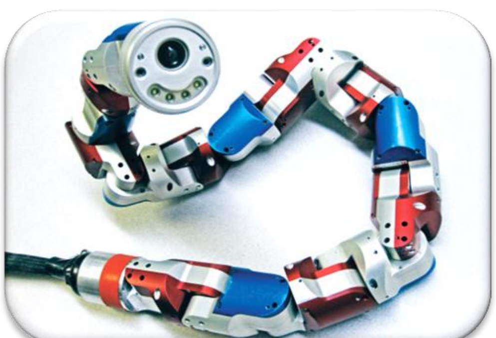
Hybrid

ALREADY NOT A GOOD CLASSIFICATION

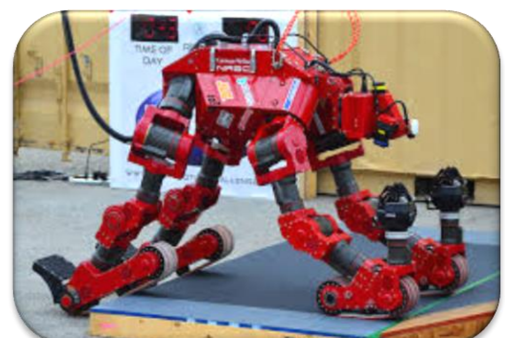


Wheeled

Legged



Whole body



Hybrid

TYPES OF WHEELED SYSTEMS (AGVS)

Carrier (Savant)

Tow (Seegrid)

Transport (Kiva)

Wheels: Steer and Drive (Aim and Go)

Fixed Axle: Differential Drive

Two wheels and a caster

Skid Steer

Omni-wheels

Mechanum wheels

Steerable Axle

Ackerman

Synchrodive

Multi-body

Indirect

Wheels: Steer and Drive (Aim and Go)

Fixed Axle: Differential Drive

Two wheels and a caster

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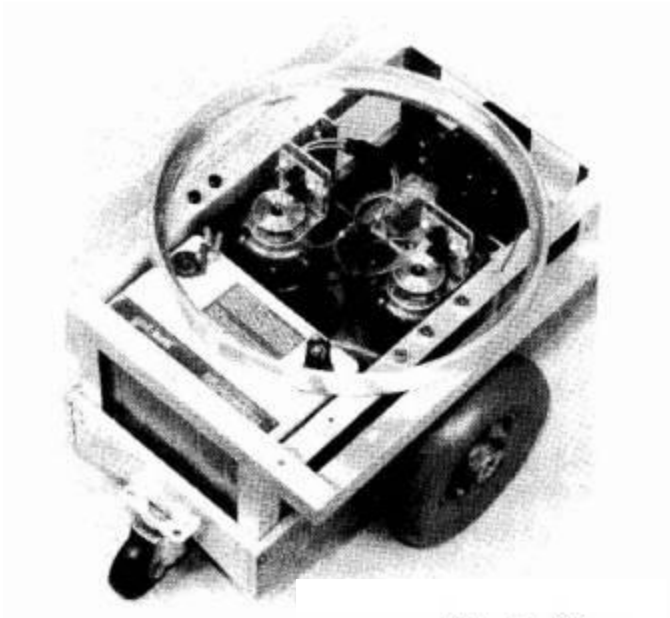
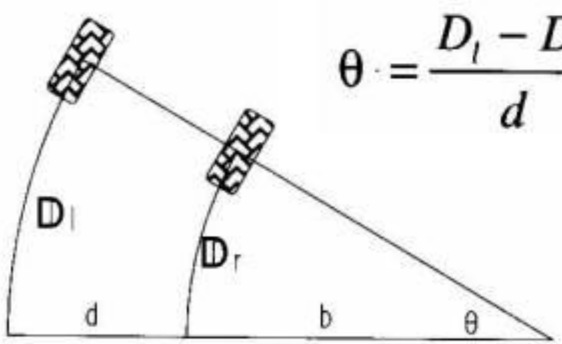
TWO WHEELS AND A CASTER



$$D = \frac{D_l + D_r}{2}$$

$$\theta = \frac{D_l - D_r}{d}$$

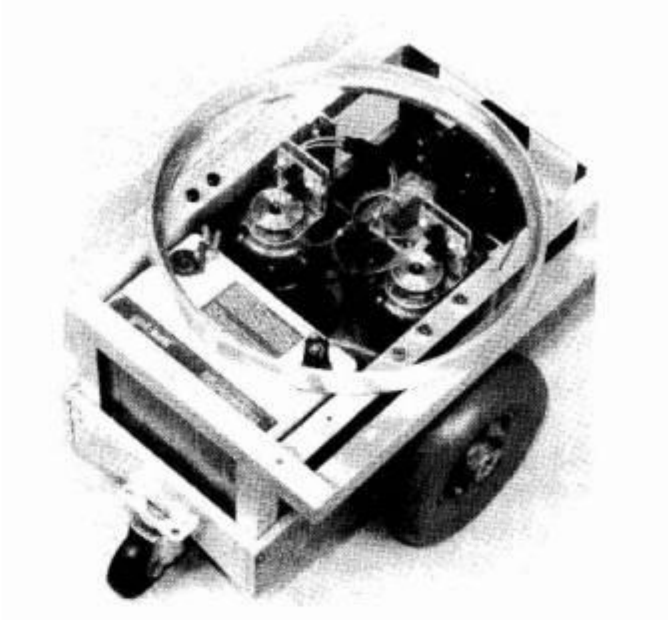


Pictures from “Navigating Mobile Robots: Systems and Techniques” Borenstein, J.

Advantages:
- Simple drive system
- Larger wheels handle bumps

Disadvantages:
- Slippage and poor odometry results
- Caster cause undesirable motion
- Careful calibration for good control
- Takes a larger wheel to handle bumps

CASTERS



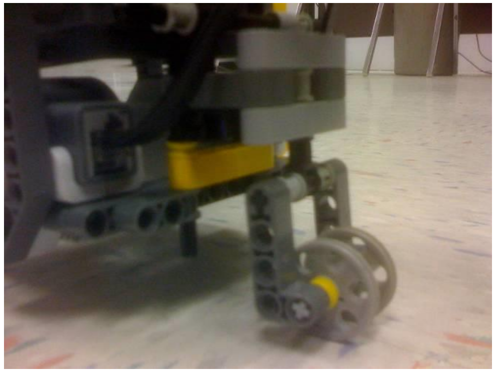
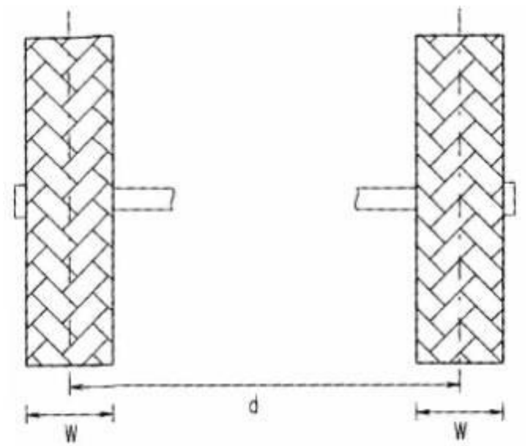
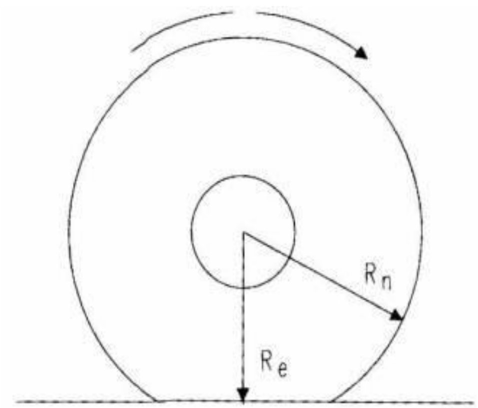


Photo courtesy of Nolan Hergert

CALIBRATION





Changing diameter makes for uncertainty in dead-reckoning error

Pictures from "Navigating Mobile Robots: Systems and Techniques" Borenstein, J.

Dragon runner

(Schempf; NREC, Automatika)

A view from the Robot

SKID STEERING

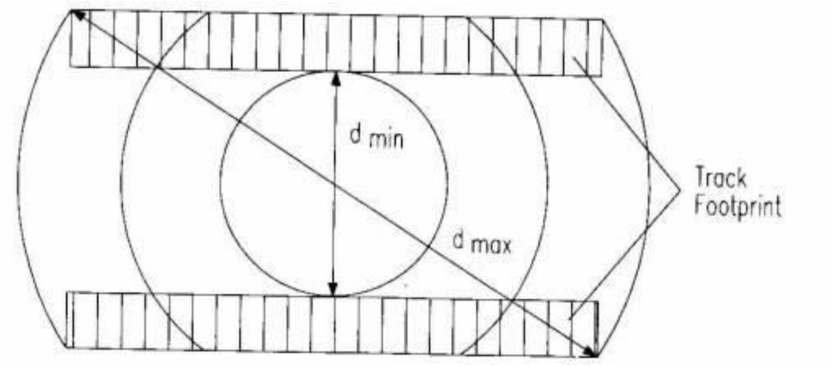
Advantages:

•Simple drive system

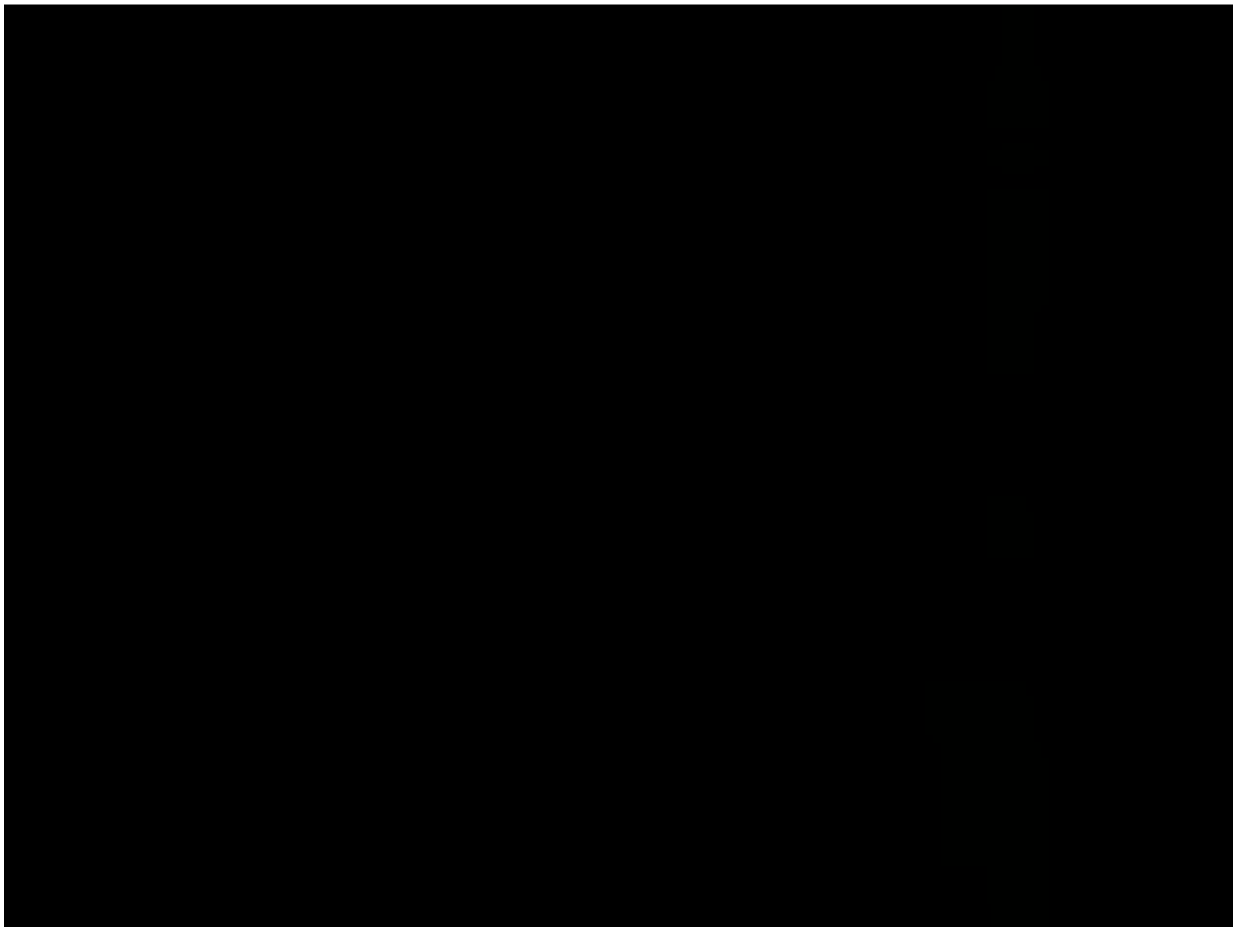
Disadvantages:

•Slippage and poor odometry results

•Requires a large amount of power to turn



IRobot, Packbot



Rescue Robot Quince（IRS、furo、Tadokoro）

TEPCO Using QUINCE

Wheels: Steer and Drive (Aim and Go)

Fixed Axle: Differential Drive

Two wheels and a caster

Skid Steer

Omni-wheels

Mechanum wheels

Steerable Axle

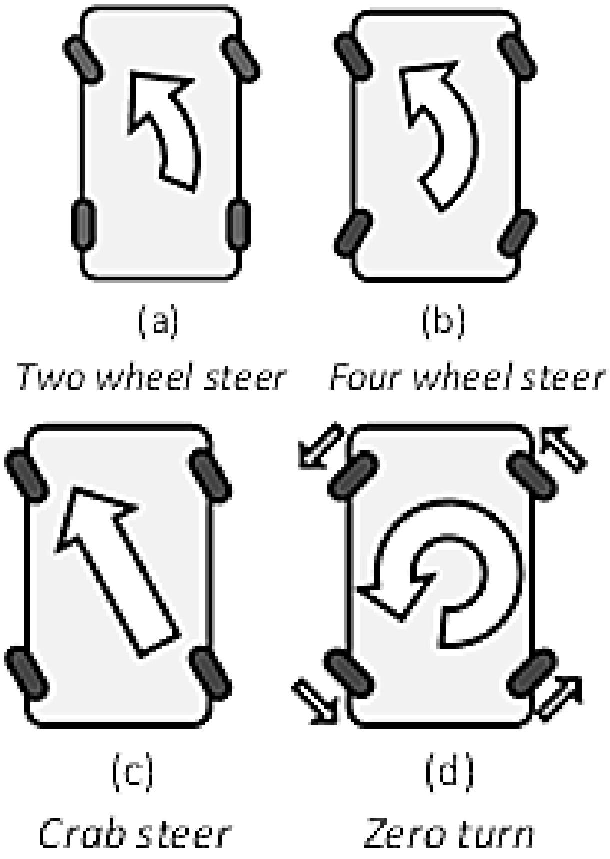
Ackerman

Synchrodive

Multi-body

Indirect

Wheels: Steer and Drive (Aim and Go)



Steerable Axle

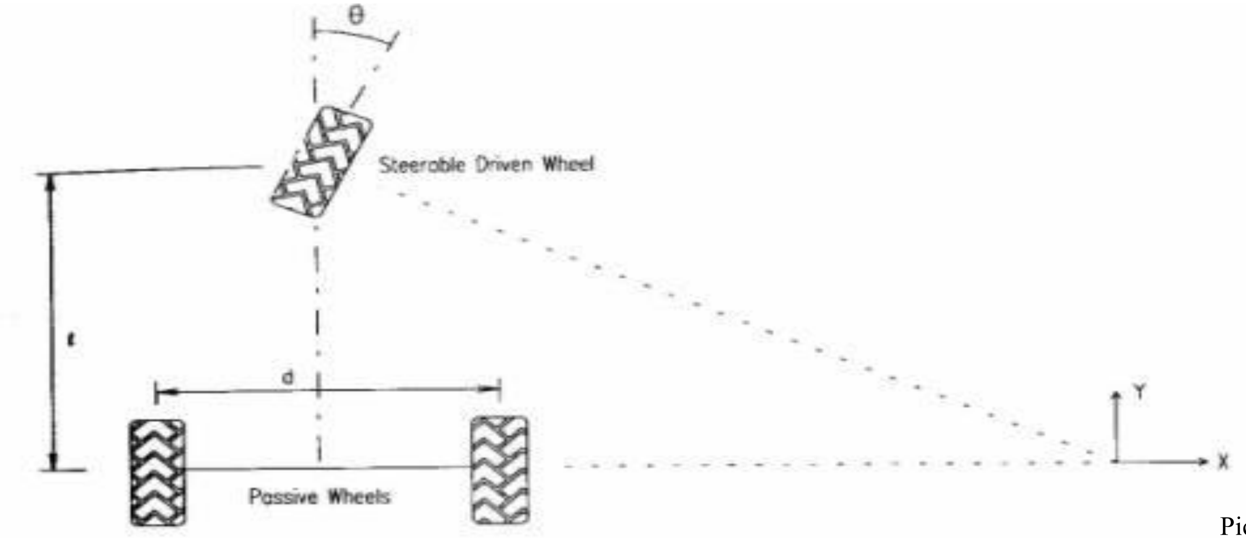
Ackerman

Synchrodive

Multi-body

Indirect

TRICYCLE STEERING



Pictures from “Navigating Mobile Robots: Systems and Techniques” Borenstein, J.

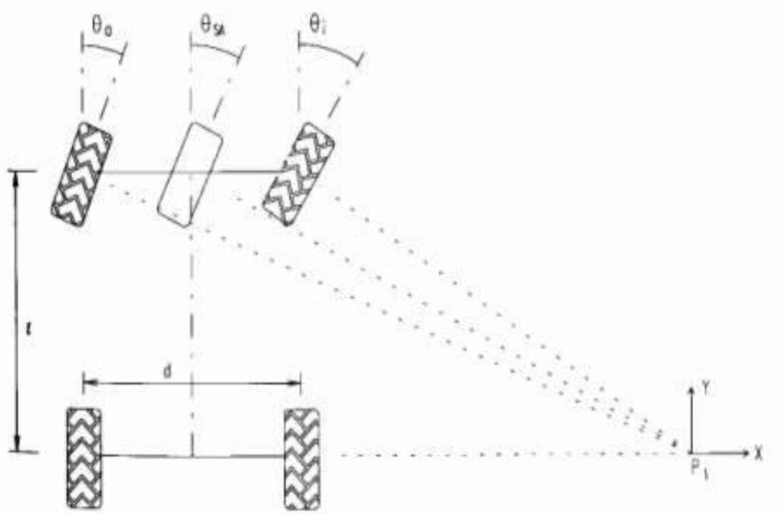
- Advantages:
  - No sliding
- Disadvantages:
  - Non-holonomic planning required

ACKERMAN STEERING

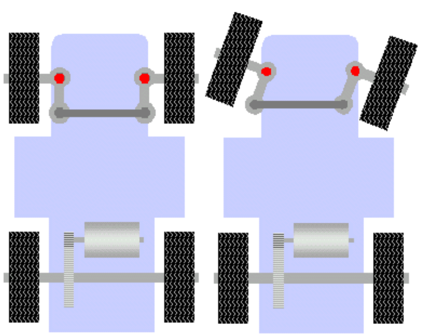
$$\cot\theta_i - \cot\theta_o = \frac{d}{l}$$

where:

θ_i = relative steering angle of inner wheel
θ_o = relative steering angle of outer wheel
l = longitudinal wheel separation
d = lateral wheel separation.

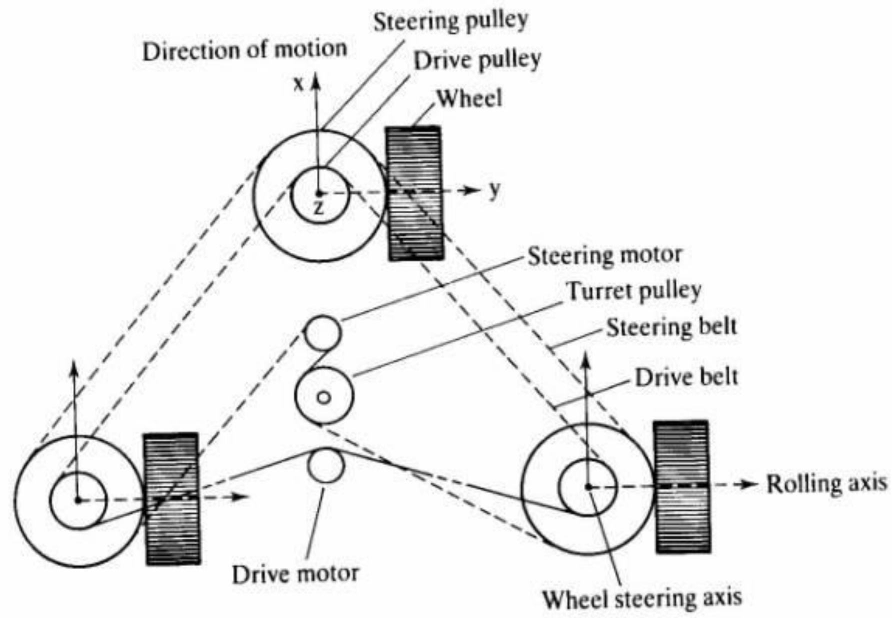


- Advantages:
  - Simple to implement
  - Simple 4 bar linkage controls front wheels
  - No slipping
- Disadvantages:
  - Non-holonomic planning required



SYNCHRODRIVE

Pictures from “Navigating Mobile Robots: Systems and Techniques” Borenstein, J.



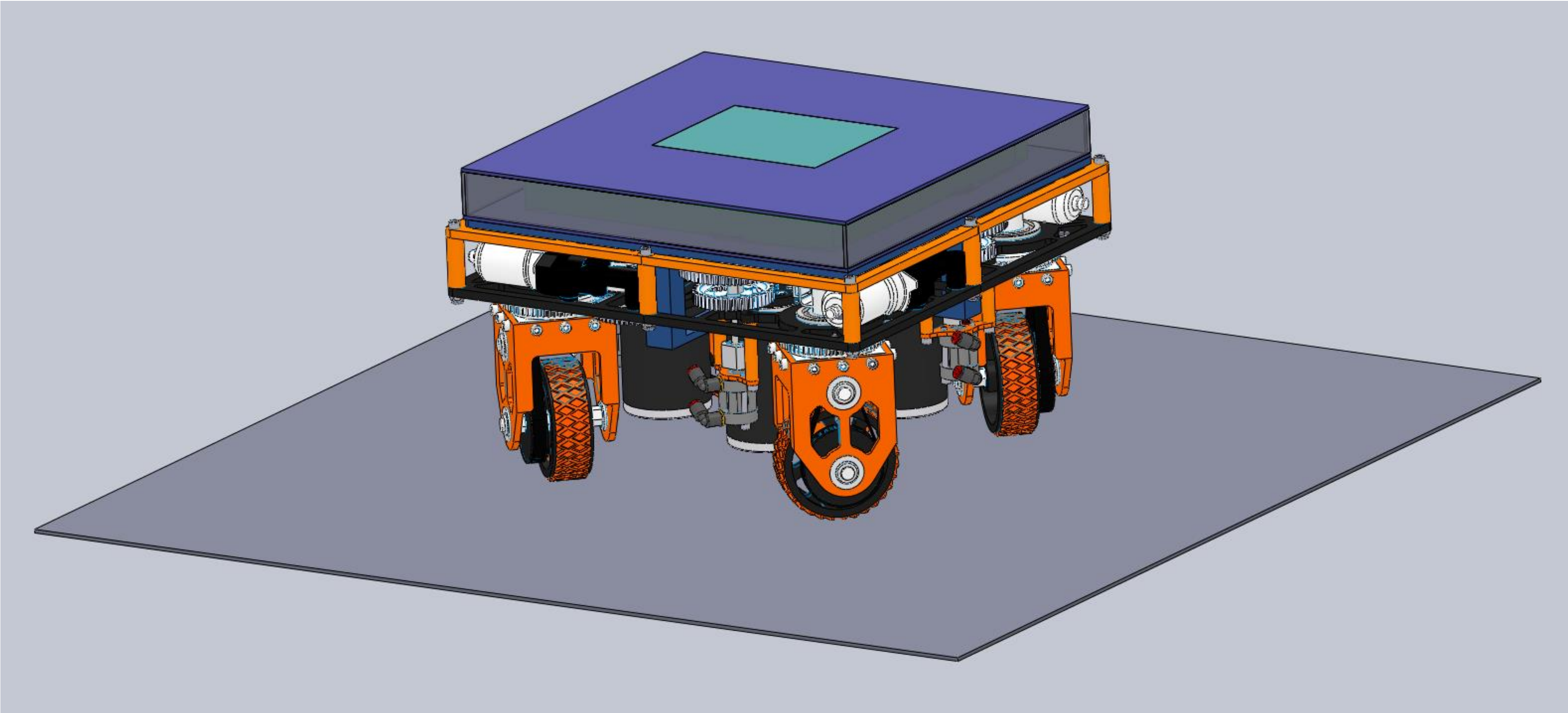
Advantages:

- Separate motors for translation and rotation makes control easier
- Straight-line motion is guaranteed mechanically

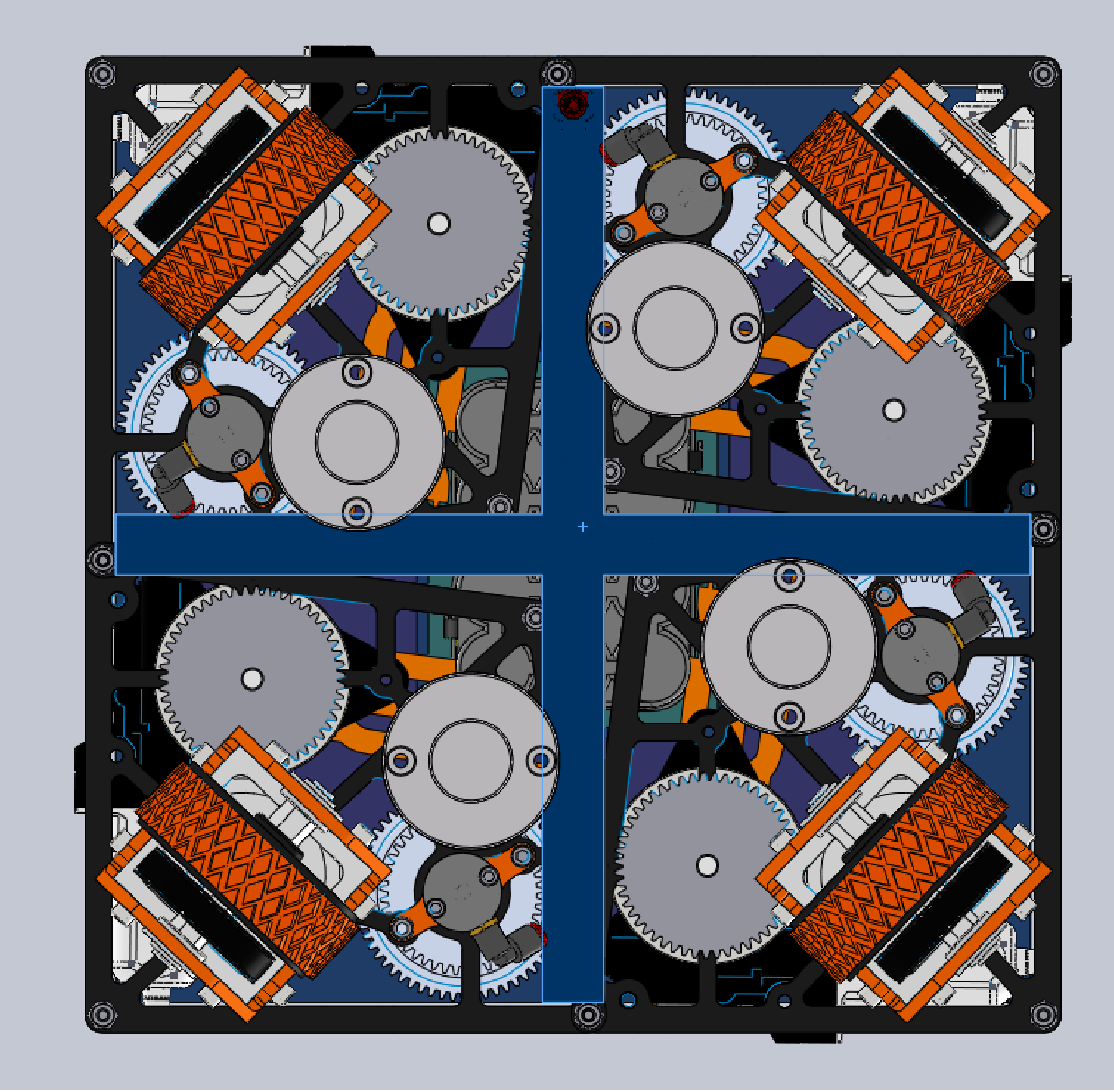
Disadvantages:

- Complex design and implementation

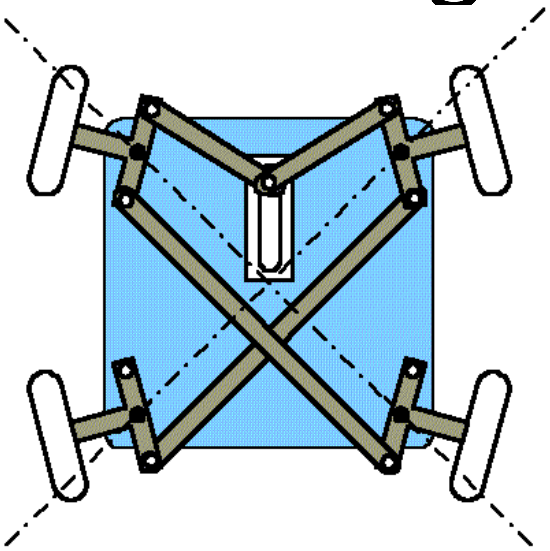
SYNCHRODRIVE



SYNCHRODRIVE (BOTTOM VIEW)



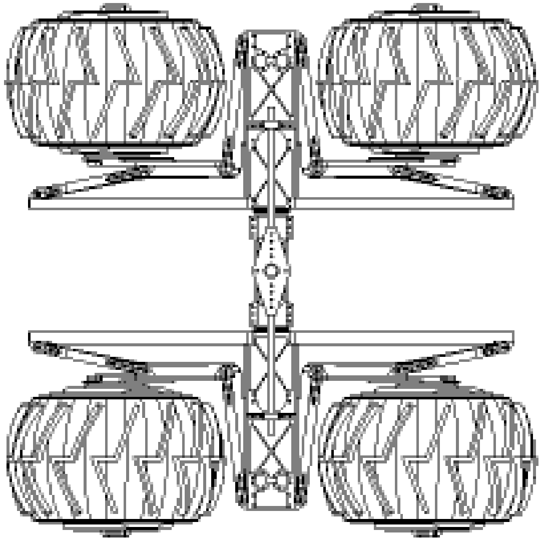
Something where Axle Can move



Advantages:
- Simple to implement except for turning mechanism

Disadvantages:
- Non-holonomic planning is required

Nomad: Red Whitaker



Internal Body Averaging Motors in the wheels

Wheels: Steer and Drive (Aim and Go)

Fixed Axle: Differential Drive

Two wheels and a caster

Skid Steer

Omni-wheels

Mechanum wheels

Steerable Axle

Ackerman

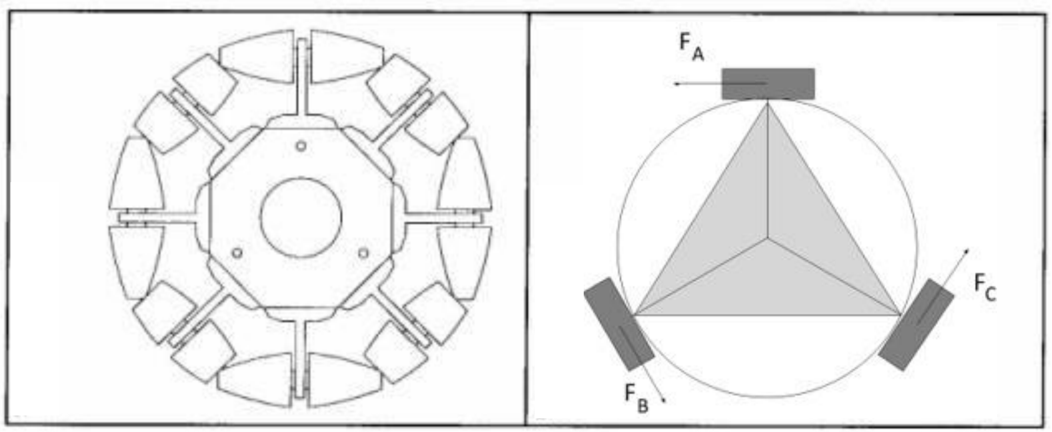
Synchrodive

Multi-body

Indirect

OMNI WHEELS

Nourkbash
Mason



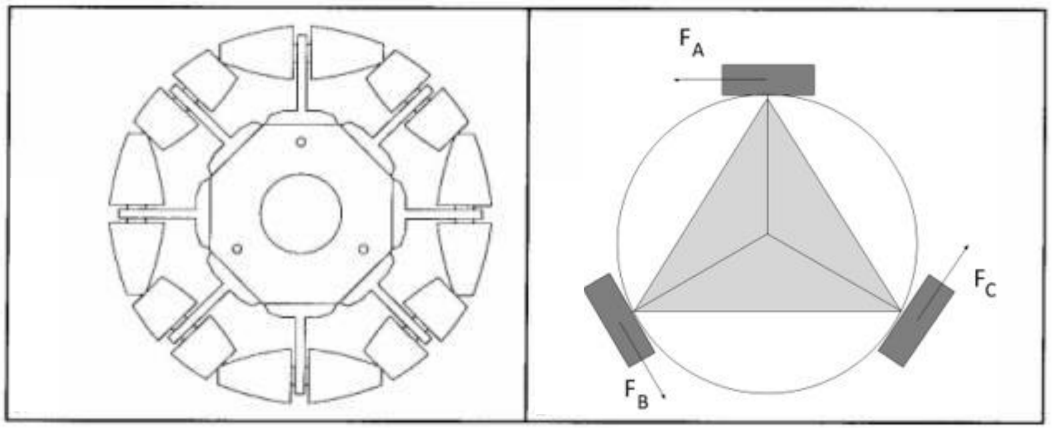
Manuela Veloso and Cobot

OMNI WHEELS

Nourkbash
Mason

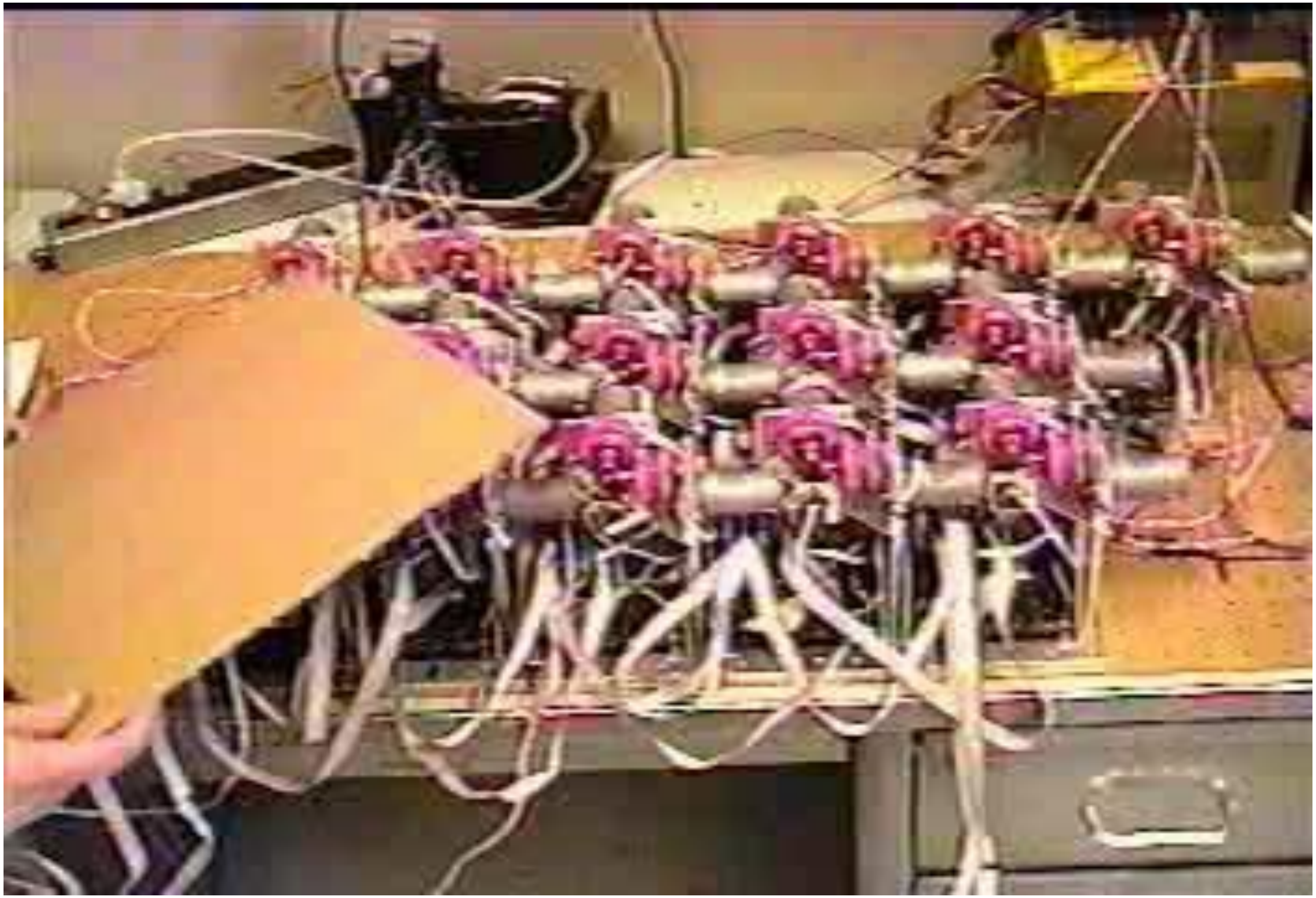
Advantages:
- Allows complicated motions

Disadvantages:
- No mechanical constraints to require straight-line motion
- Complicated implementation
- Does not hand bumps well

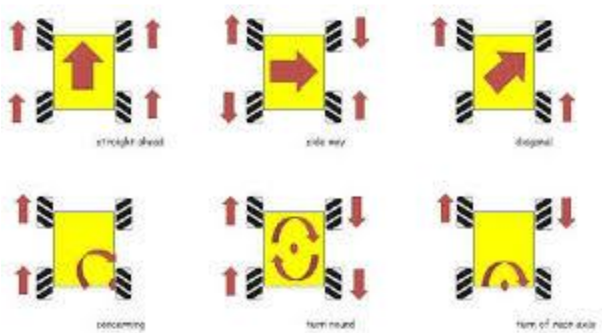


Manuela Veloso and Cobot

VIRTUAL VEHICLE



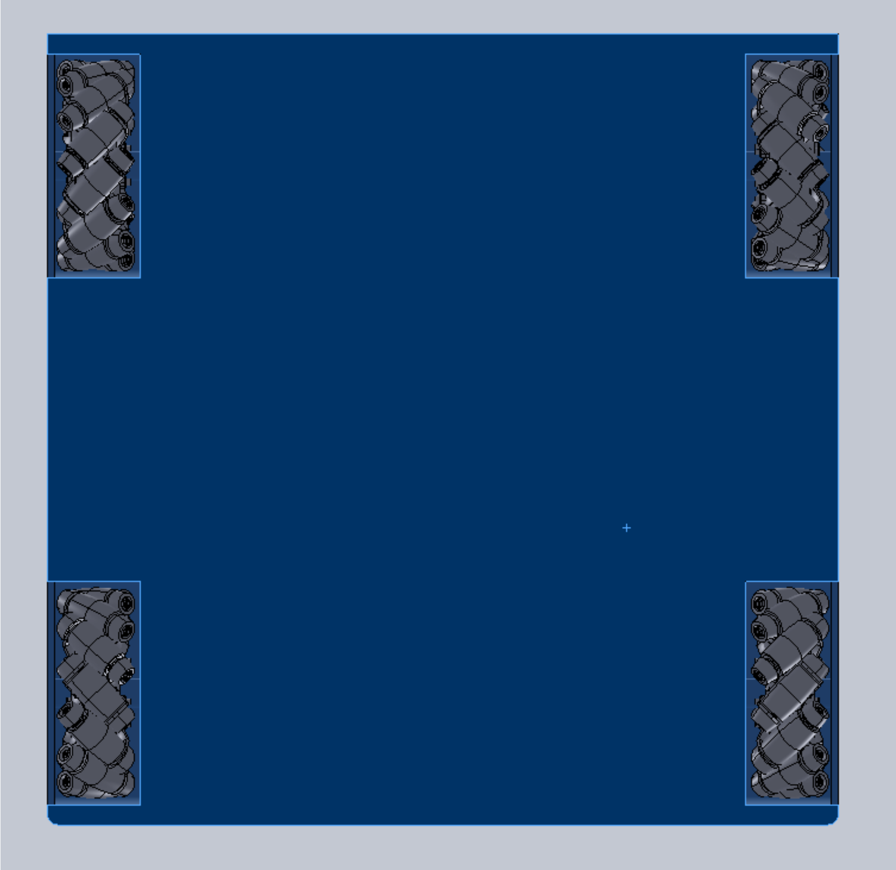
MECANUM WHEELS



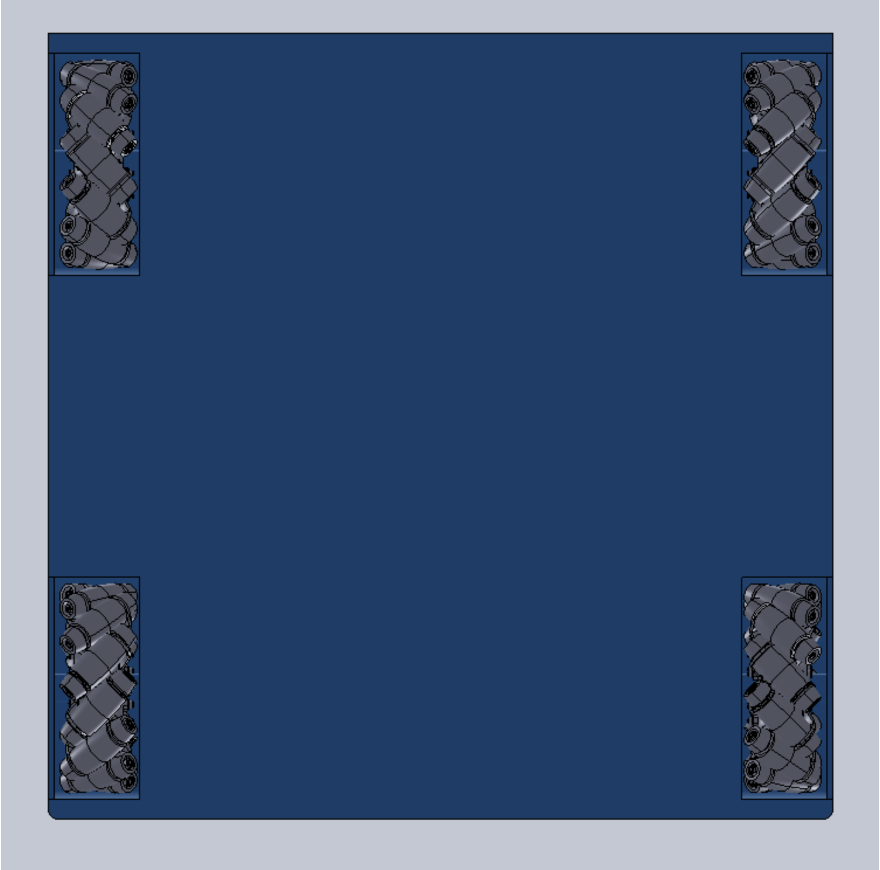
Advantages:
- Allows complicated motions

Disadvantages:
- No mechanical constraints to require straight-line motion
- Complicated implementation
- Does not hand bumps well

X'S AND O'S



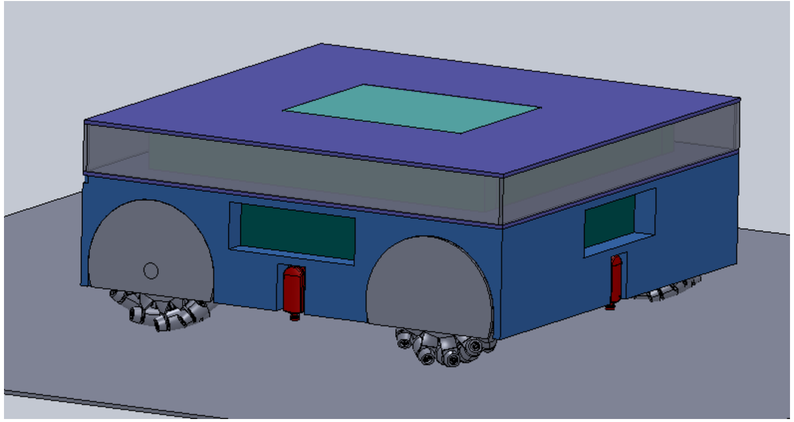
"O" Configuration

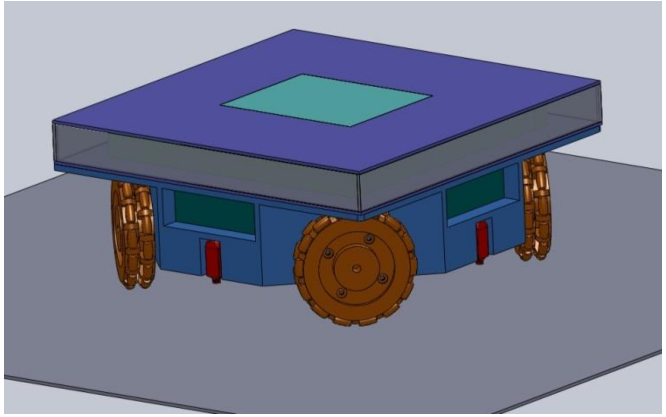


"X" Configuration

Bottom View

OMNI VS MECANUM WHEELS

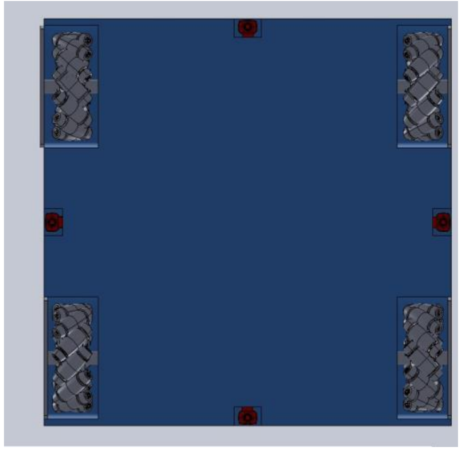


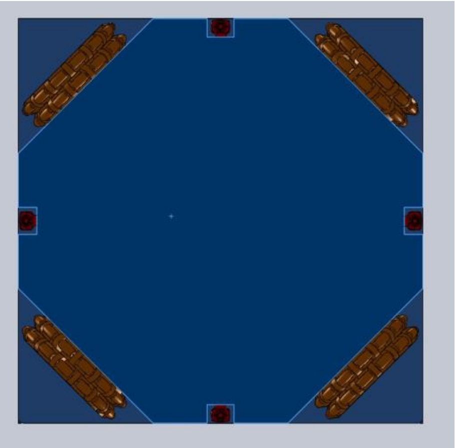


Climbs ramps easier

More power efficient

Fit in a normal frame





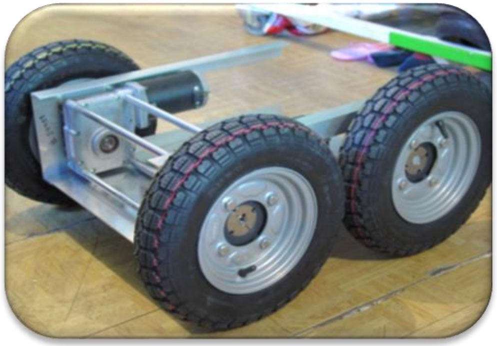
Cheaper

More finicky

True omnidirection motion

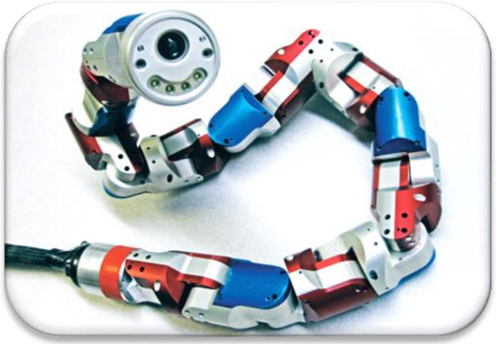
Point of contact change is greater

CLASSIFICATIONS

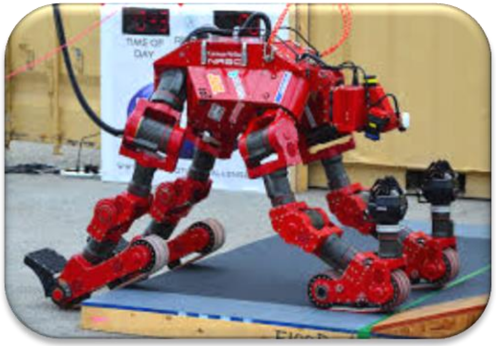


Wheeled

Legged



Whole body



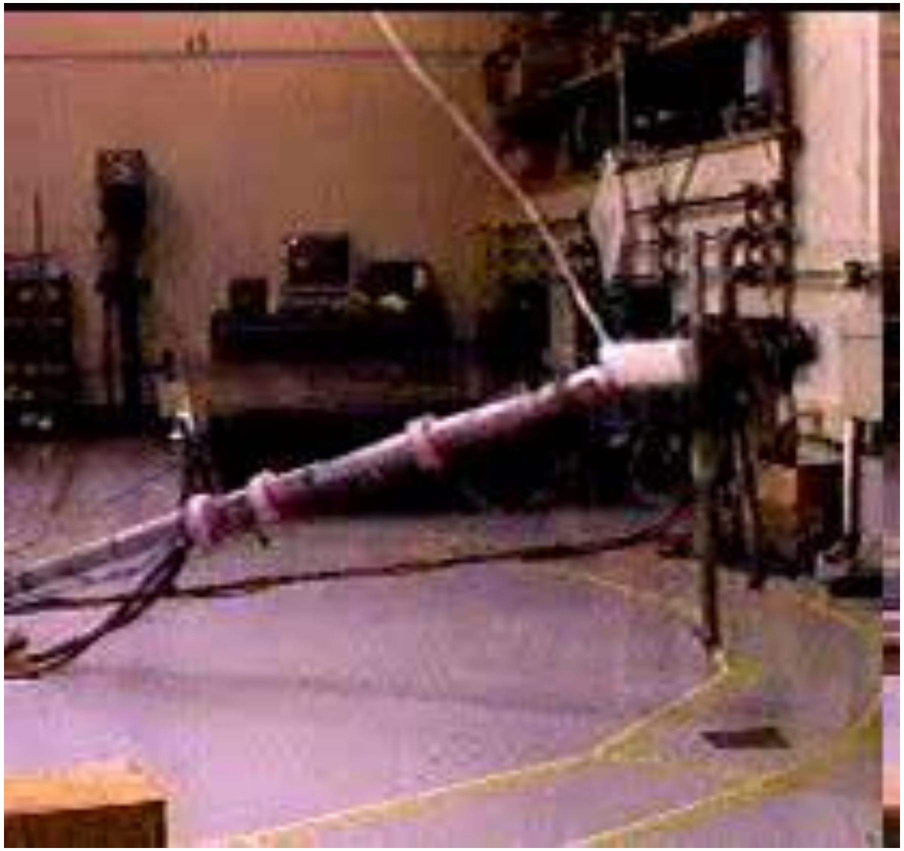
Hybrid

Asimo

Early Raibert robots

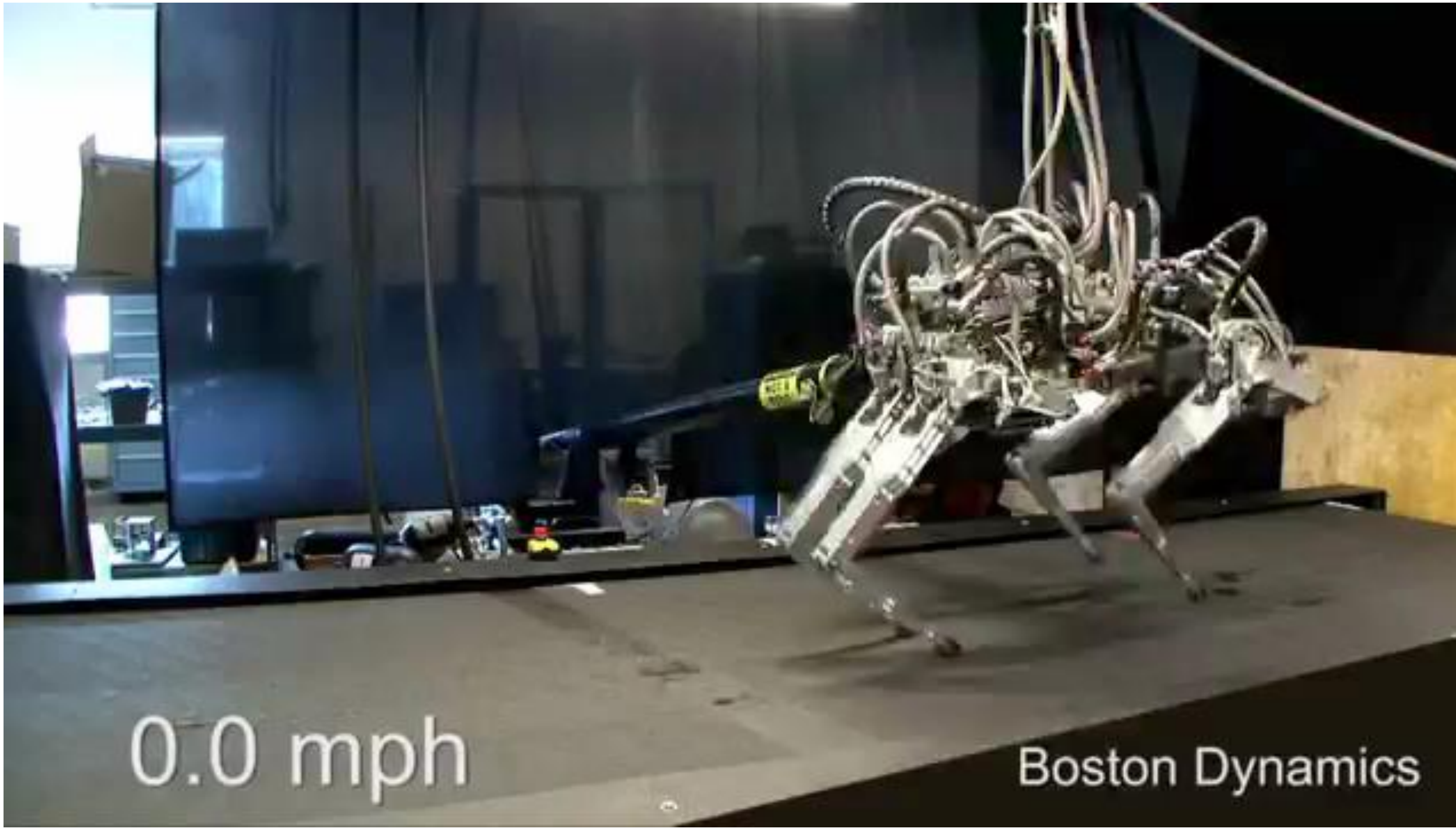
Quadruped, 1984-1987

Planar Quadruped (Hodgins, 1985-1990)



Boston Dynamics Big Dog

Cheetah



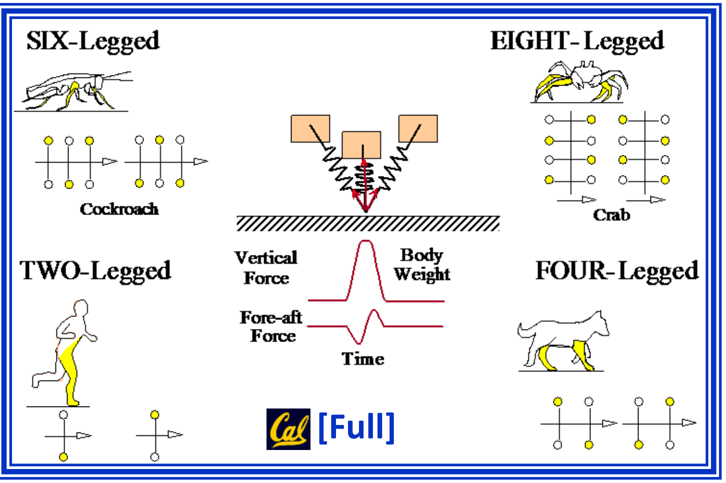
Cheetah Robot runs 28.3 mph; a bit faster than Usain Bolt

Wildcat

BDI Petman

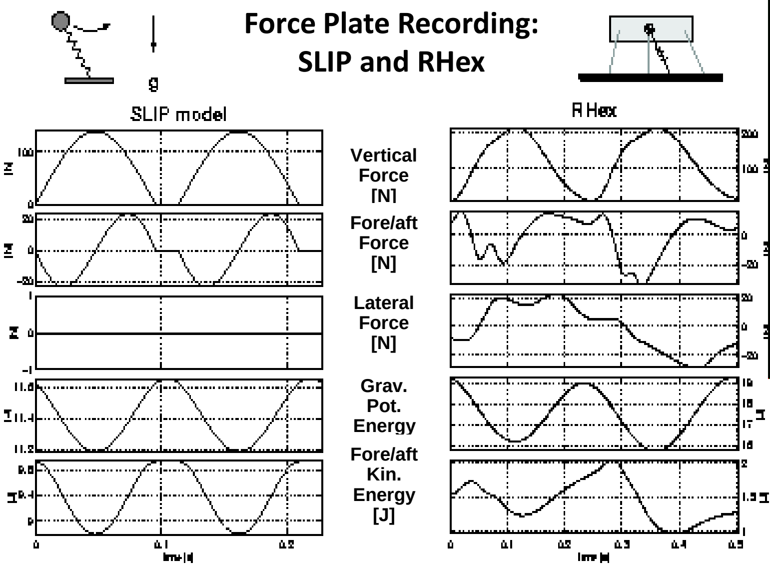
RHex

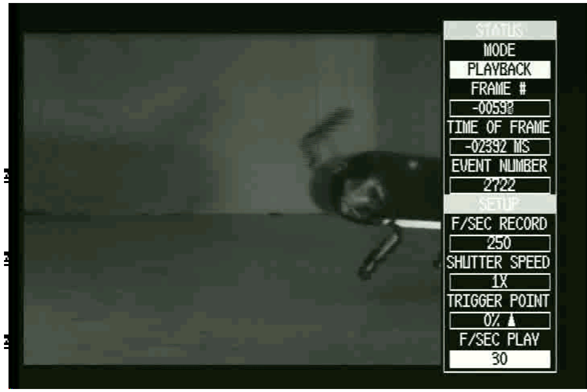
Running Animals (and RHex) Anchor A Pogo Stick



Biomechanics Literature:
- all animal runners studied to date
- have ground force reaction patterns
- that resemble a pogo stick

RHex Literature:
- Well tuned robot
- With large aerial phases
- exhibits ground reaction force patterns
- that resemble a pogo stick



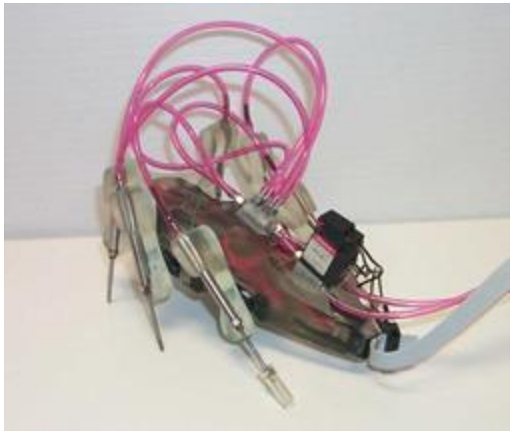


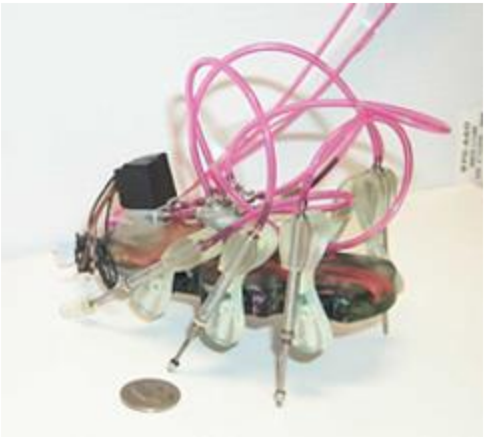
Tuned RHex anchors Spring Loaded Inverted Pendulum (SLIP)

[Altendorfer, *et al*. **Autonomous Robots** 2001 **11**: 207-213]

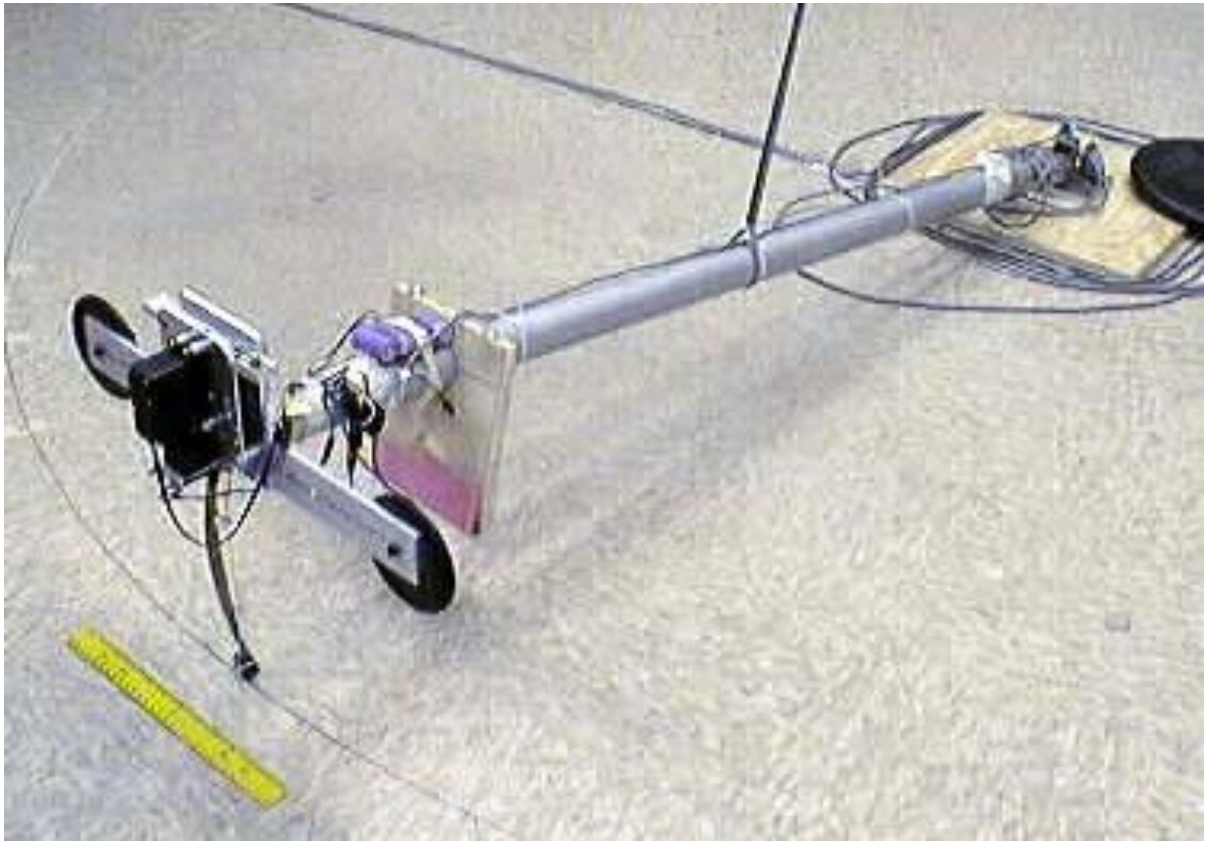
Thanks to Dan Kodischek

Sprawlita





Bowleg Hopper (Brown, Zeglin, Mason)

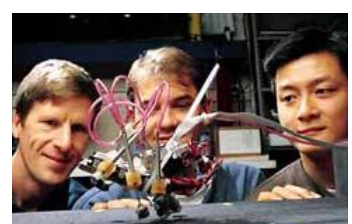


Bow Leg Climber

(Degani, Brown, Lynch, Mason, Choset)

Benefits of Compliance: Robustness

- Handle unmodeled phenomena
- Regulate friction (e.g. on textured surfaces)
- Minimize large forces due to position errors
- Overcome stiction
- Increase grasp stability
- Extra passive degree of freedom for rolling
- Locally average out normal forces (provides uniform pressure, no precise location)
- Lower reflected inertia on joints [Pratt]
- Energy efficiency (probably not for snakes)



Wheels vs. Legs

- Are legs better than wheels?

Wheels vs. Legs

- Are legs better than wheels?
- Are legs optimal?

With respect to what?

- Are legs better than wheels?
- Are legs optimal?

Metrics

Are wheels good?

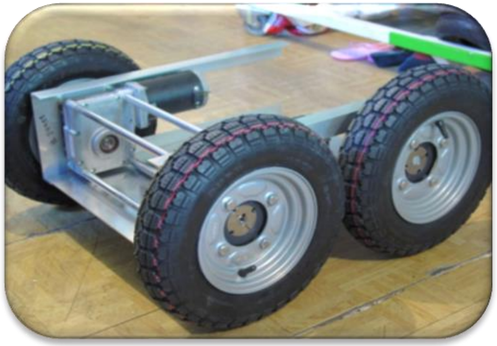
- Power efficient
- Constant contact with (flat) ground (no impacts)
- Easy and inexpensive to construct
- Easy and inexpensive to maintain
- Easy to understand
- Minimal steady-state inertial effects

Can only go on flat terrains?

Design Tradeoffs with Mobility Configurations

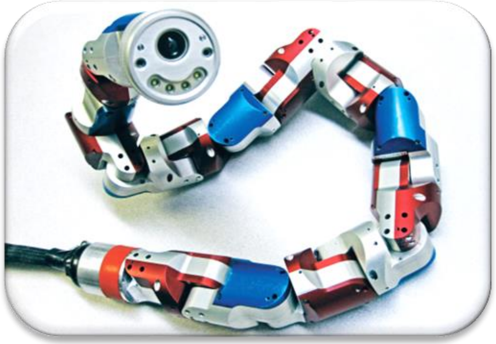
- Maneuverability
- Controllability
- Traction
- Climbing ability
- Stability
- Efficiency
- Maintenance
- Environmental impact
- Navigational considerations
- Cost
- Simplicity in implementation and deployment
- Versatility
- Robustness
- Accuracy
- Elegance? (if we are selling robots)
- Speed
- Manufacturability
- Safety

ALREADY NOT A GOOD CLASSIFICATION

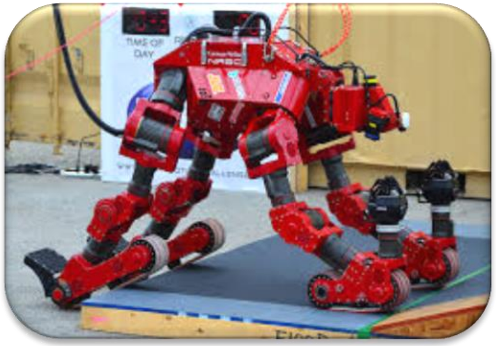


Wheeled

Legged



Whole body



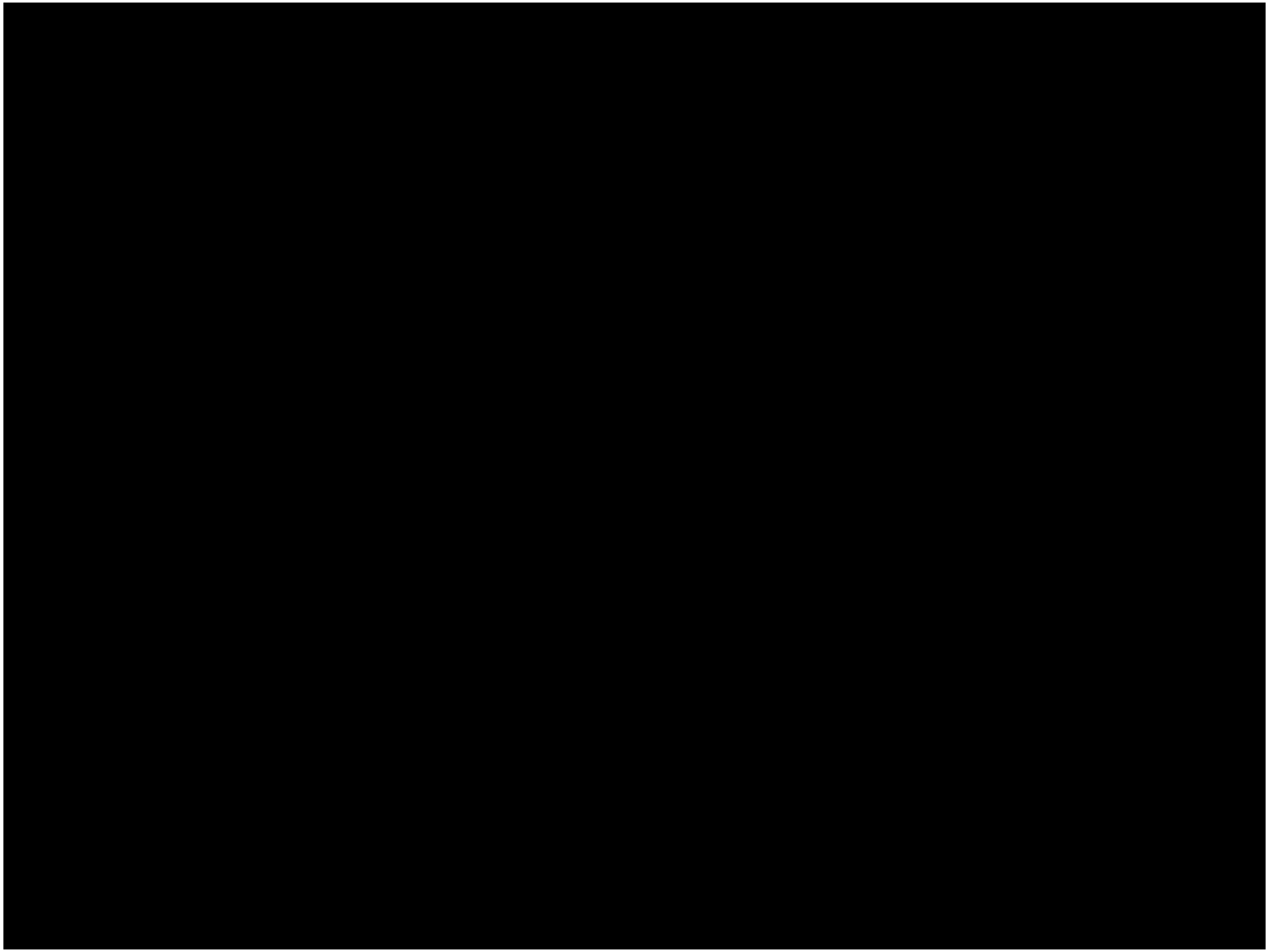
Hybrid

What’s a wheel?

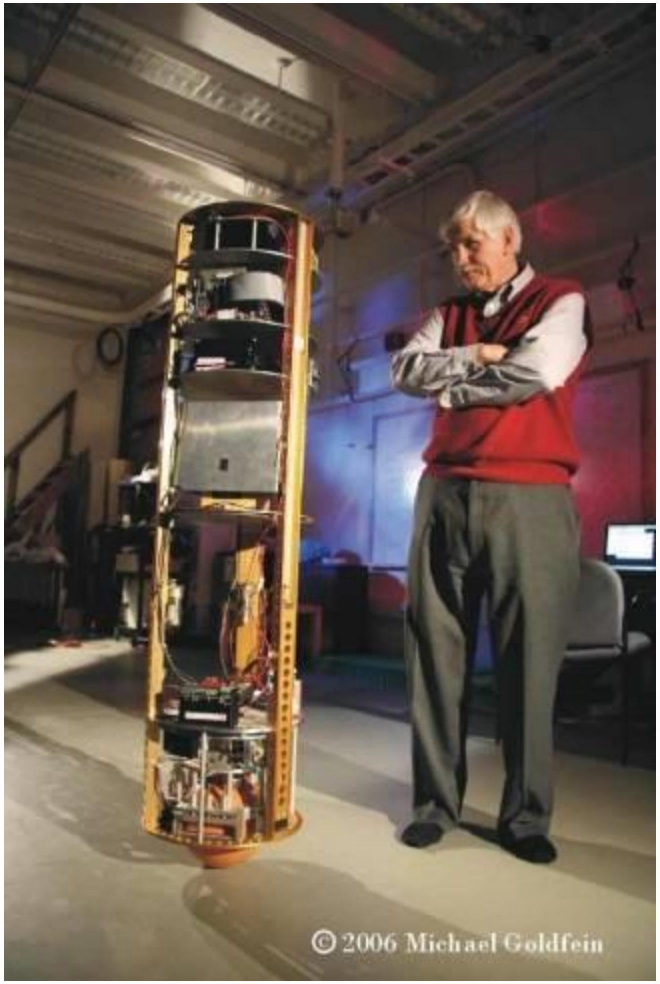
- Single wheel
- Ball
- Gait (think Rhex and Snake)

- And of course, tank treads

Gyrover (Brown)

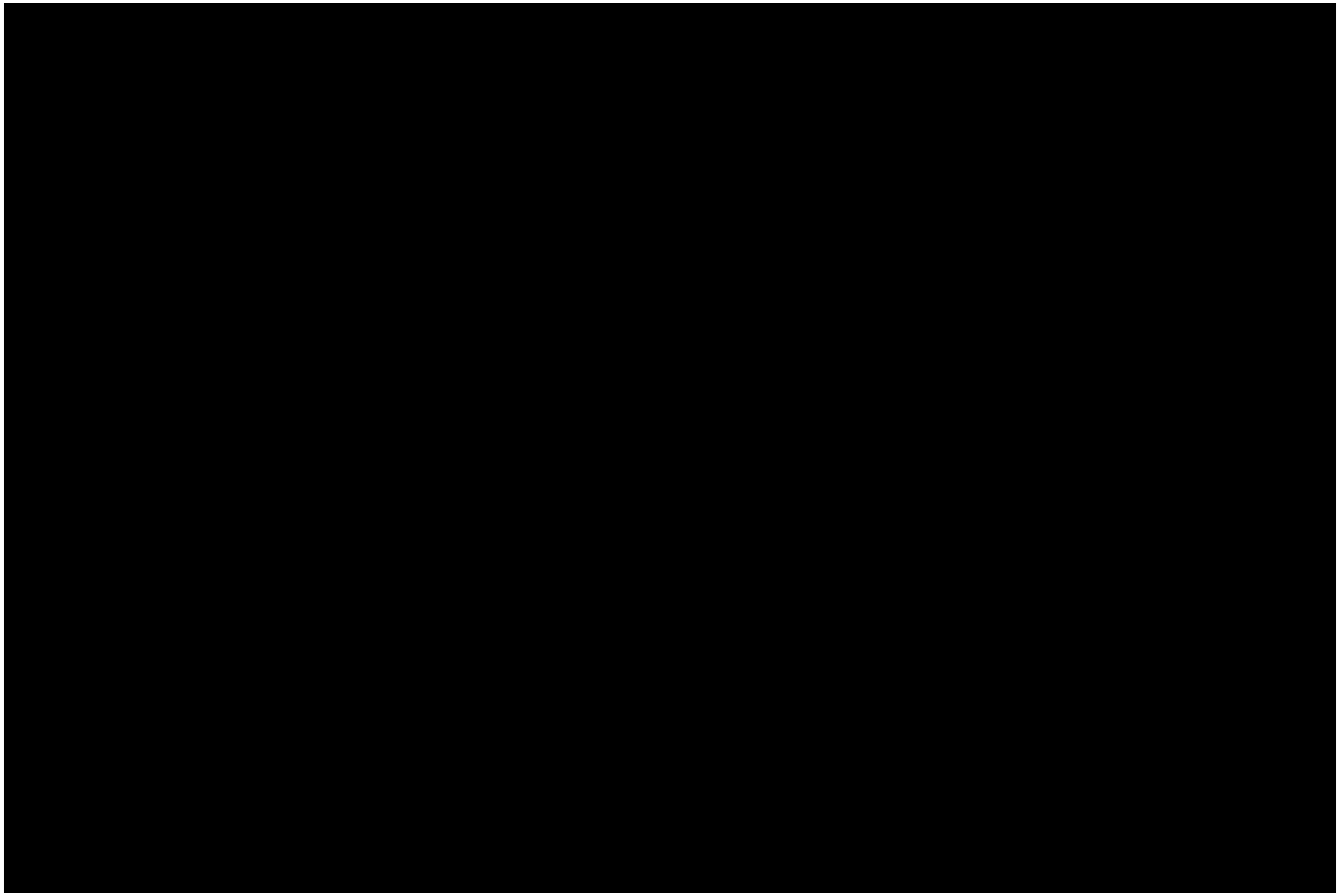


Ballbot, Ralph Hollis



“A Dynamically stable Single-Wheeled Mobile Robot with Inverse Mouse-Ball Drive."

NXT Ballbot

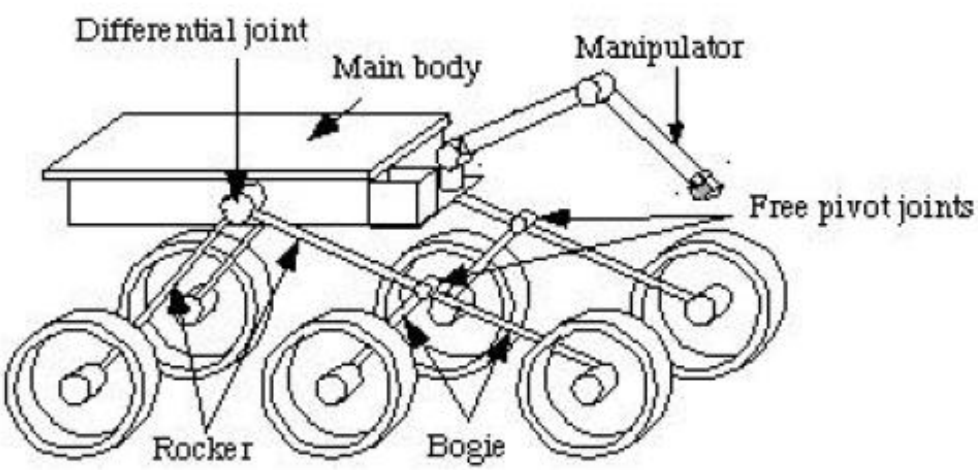


Horizontal and Vertical Motion

UGCV (Crusher)
[Bares/Stentz, REC]

Recon Scout

Rocker Bogie



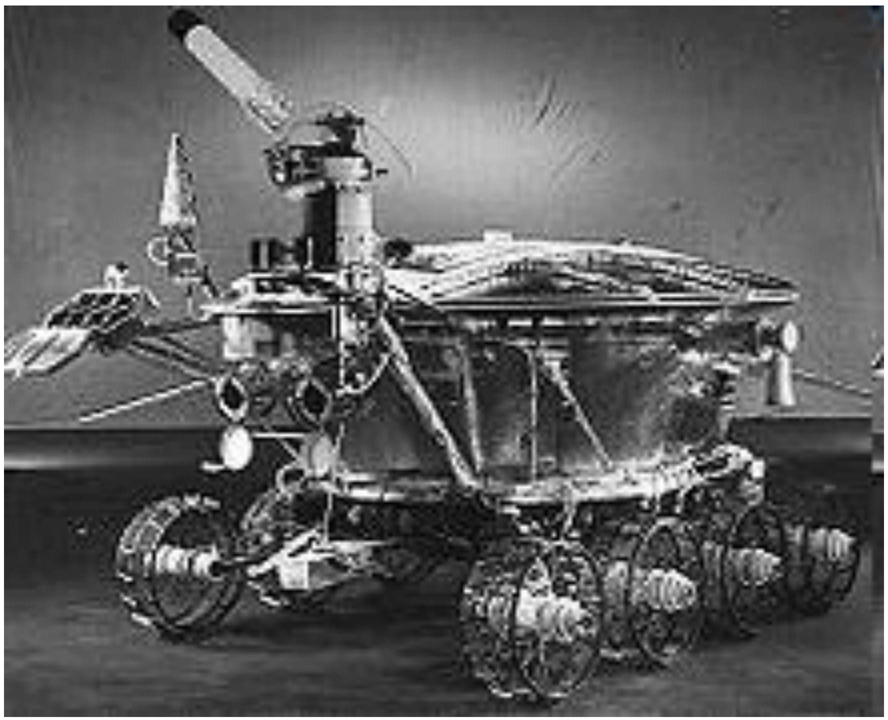
Taken from Hervé Hacot, Steven Dubowsky, Philippe Bidaud

http://www.robotthoughts.com/index.php/lego/archives/2007/07/20/lego-nxt-rocker-bogie-suspension/

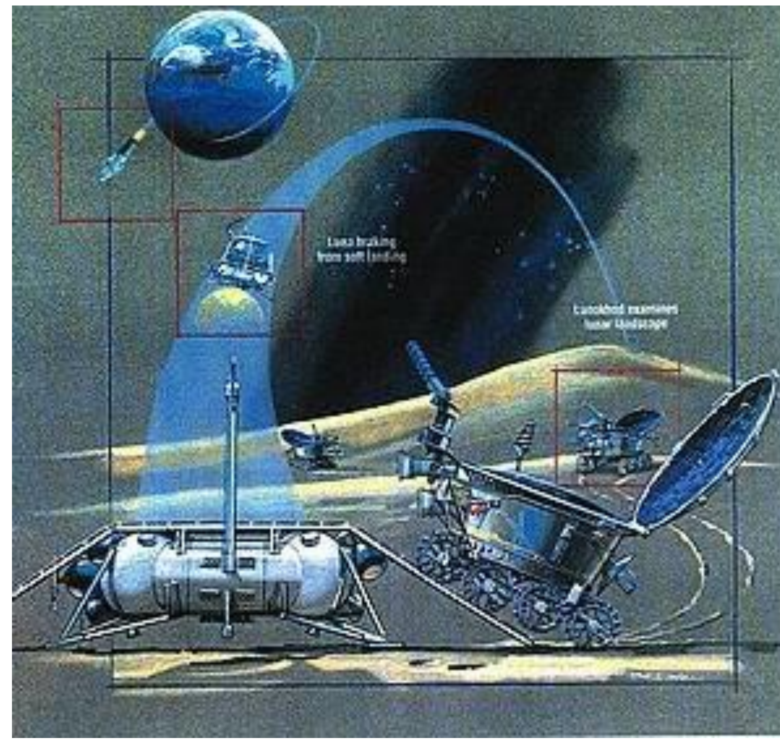
http://www.huginn.com/knuth/blog/2007/06/24/lego-nxt-rocker-bogie-suspension/

Rocker Bogie

Lunakod: Were we first?



In 322 days, L1 traveled 10.5km
Both operated 414 days, traveled 50km
In 5 years, Spirit and Opportunity 21km

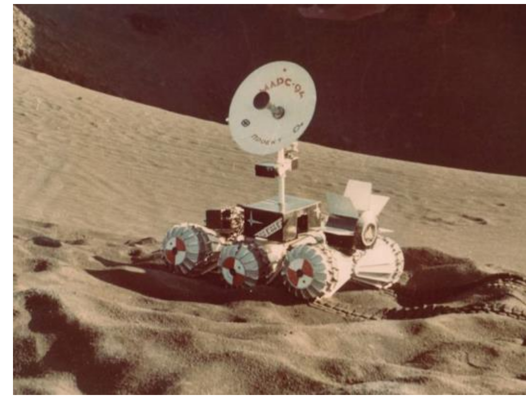


1969 Lunokhod 1A was destroyed at launch
1970 Lunokhod 1landed on the moon
1973 Lunokhod 2 landed on the moon

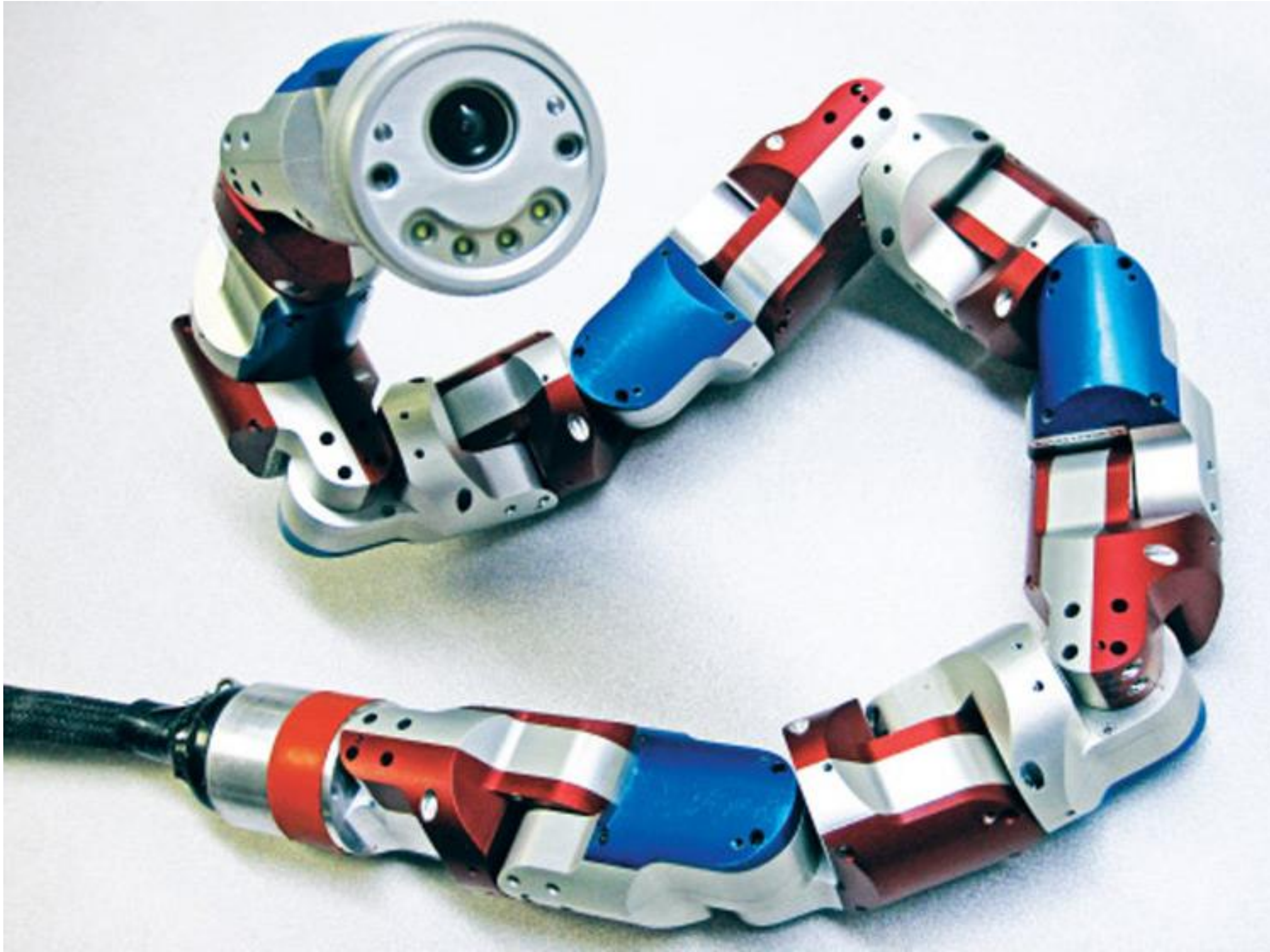
Lunakod


14:16
CET
RT
IRAQI PRESIDENT REFUSES TO SIGN OFF
ON DEATH SENTENCE FOR TARIQ AZIZ
NEWS
S BEFORE END OF YEAR.
IRAQI PRESIDENT SAY

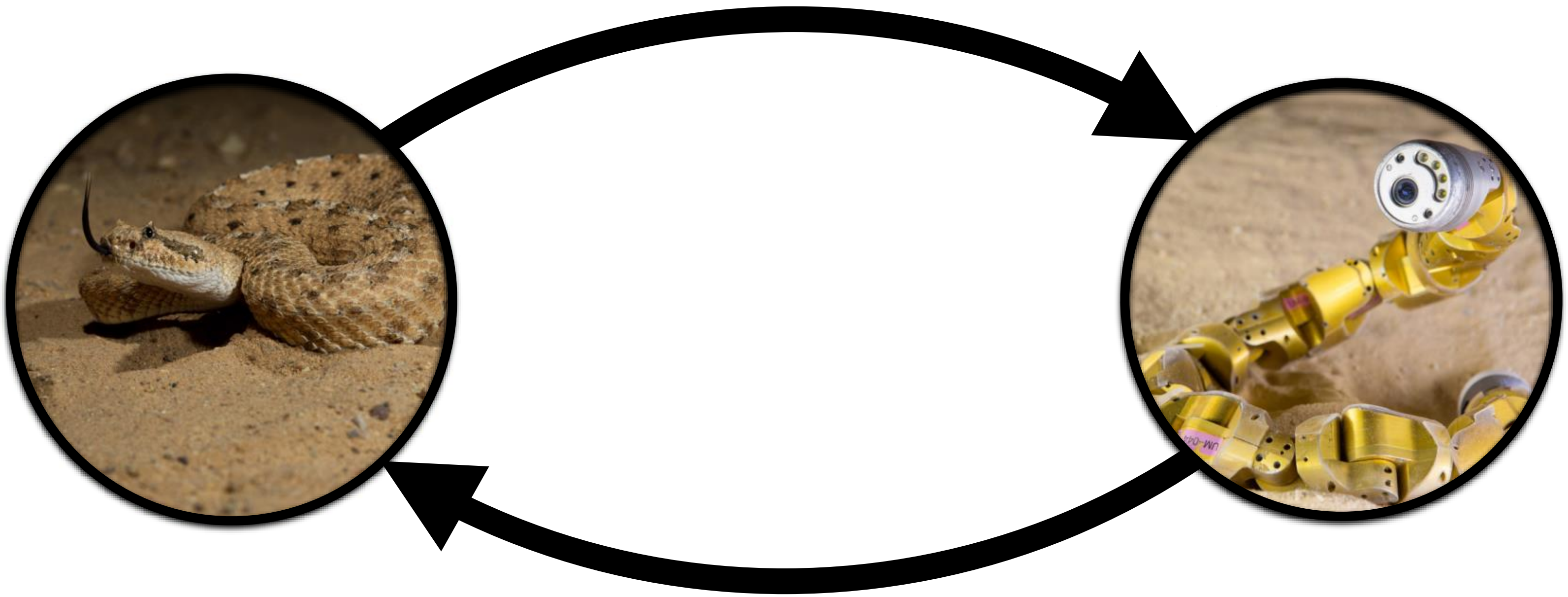
Marsakhod



Marsokhod unskillful operator control



From Biology to Robotics and Back



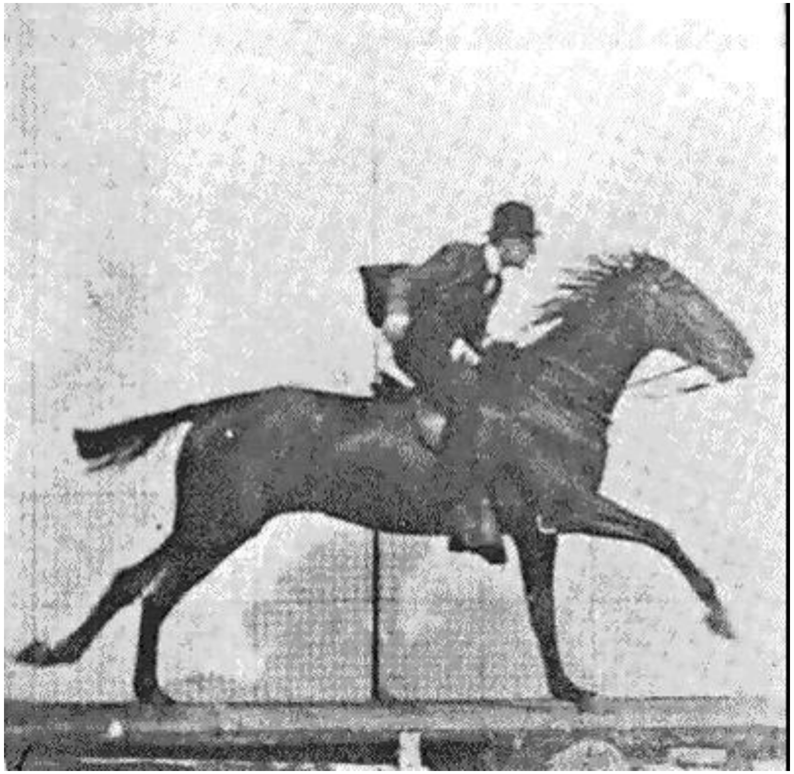
Howie Choset, Chaohui Gong, Matt Travers, Dan Goldman, Ross Hatton, Henry Ashtley

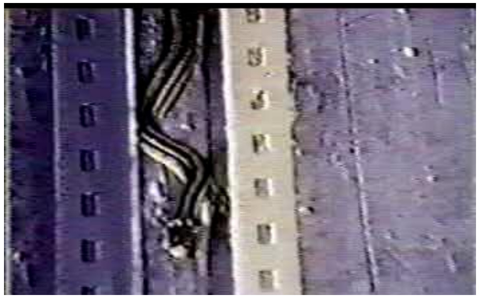
Gaits

$$Q = G \times M$$

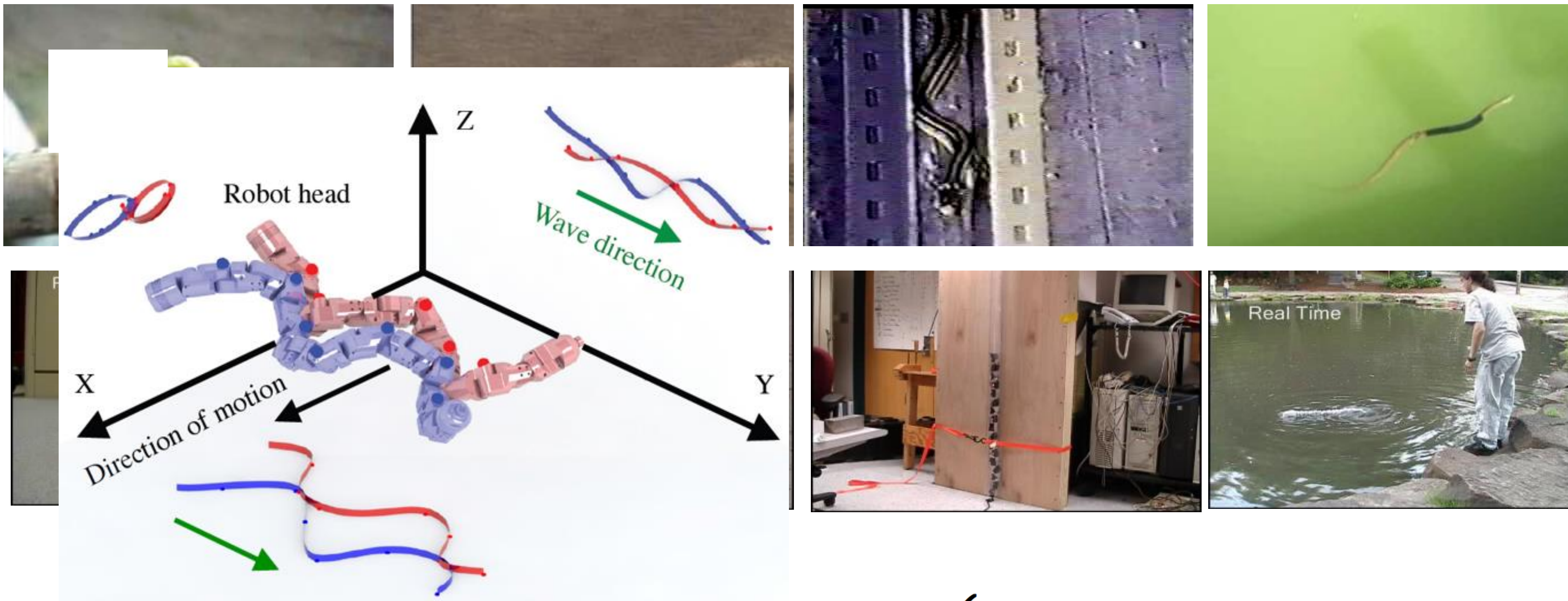
$$\begin{aligned} \phi \quad &: \quad \mathbb{R} \to M, \\ & \quad t \mapsto r, \end{aligned}$$

$$\begin{aligned} \phi(t) \quad &= \quad \phi(t + \tau) \\ & \quad \tau \in \mathbb{R} \end{aligned}$$





Compound Serpenoid Curve



$$\alpha(n,t) = \beta + A\sin(\theta)$$
$$\theta = \Omega n + \omega t$$

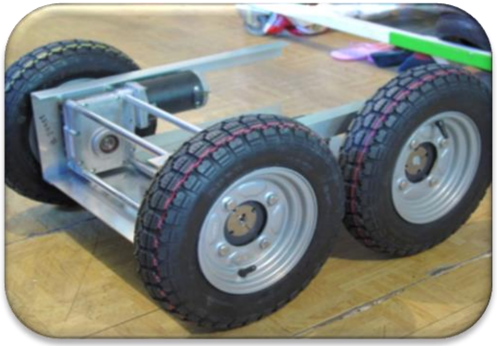
$$\alpha(n,t) = \begin{cases} \beta_{\text{odd}} + A_{\text{odd}} \sin(\theta_{\text{odd}}) \\ \beta_{\text{even}} + A_{\text{even}} \sin(\theta_{\text{even}} + \delta) \end{cases}$$

$$\theta_{\text{odd,even}} = (\Omega_{\text{odd,even}} n + \omega_{\text{odd,even}} t),$$

SAIC/CMU Snake

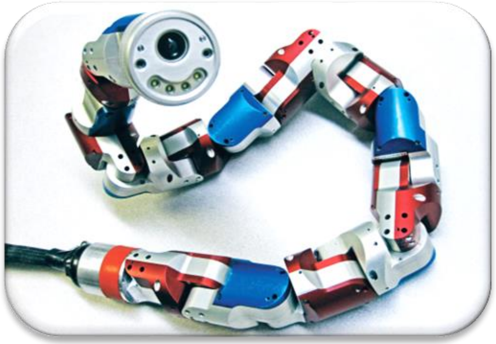
Are snakes better than legs?

ALREADY NOT A GOOD CLASSIFICATION

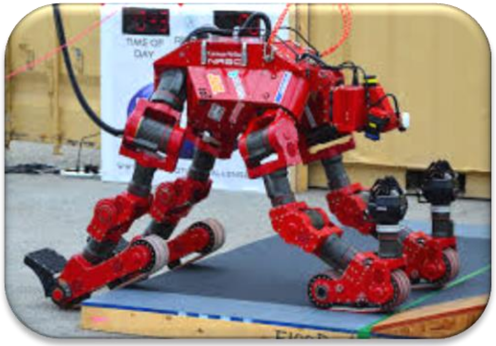


Wheeled

Legged



Whole body



Hybrid

Mobile Manipulators

- Romeo and Juliet
- HERB
- Boeing

Themes

- Drive and Steer
- Horiz and vert

Metrics

Standard metrics here

Lisa Slide here

Original email 12-24-2014

I was looking for something general and not specific to the Foxybots.

I thought there were other criteria than the ones you listed in Part 5.

We should also just create a list of all types of wheeled mobile bases

Wheel configurations
1. differential drive
2. skid steer
3. synchrodrive
4. omni-wheel based
5. mechanum wheel based

Suspension
1. none / soft wheels
2. springs, shock absorbers
3. kinematic - rocker bogie, Nomad, other mechanisms

What other classes should we consider??
Howie

END

Robot	Purpose	Size	Weight	Payload	Speed	Tech	Drive
RMT Robotics	Transport	40” Diameter 20” Height		Trays & Crates. Shelf or motorized rolers	1.5m/s	LIDAR, SLAM, path replanning, remote “call buttons”	2 Diff
Seegrid	Forklift/pulling	Large		Pallets		Stereo cameras, SLAM, LIDAR/SICK 15cm virtual bumper	
Robotiq	Lifting Box	Small		>2kg	1m/s	QR Codes, arm on base	2 Diff
Adept Tech.			132lb		1.8m/s	Batteries=19hrs, traversable gap=15mm, multiple payload platforms, LIDAR, contact	2 Diff
Vehicle Tech. (various models)	Platform	42x28” 86-48”	500-5500lb	1000-20000lb	1-2m/s	Wireless controller, no high level functions provided	4 wheel Omni
Kuka	Transport /arm	Large				LIDAR/SICK, dockable	Many omni wheel
Kuka 2 OmniRob	Platform/arm	1.2x0.7x0.6m	250kg	400kg	1m/s	LIDAR/SICK, SLAM	4 wheel omni
Clearpath Husky	Rugged Platform	0.99x0.67m	50kg	75kg	1m/s	Outdoors	4 diff
Hannover Messe	Platform	0.58x0.7x0.6m	60kg	50kg	1.4m/s	15mm max step, 24 ultrasonic range, contact	diff
iRobot	Tele-Presence	Human					

Robot	Purpose	Size	Weight	Payload	Speed	Tech	Drive
Neobotix	Transport	Small-medium		Crates 100-500kg		LIDAR/SICK	
Eagle	Transport	Small-medium		Crates		Ultrasonic??	
Aethon (Tug)	Transport	Medium		1000lb		LIDAR & 27 sonar+IR, Auto charge/dock, wifi talks to elevators, etc..	
Blue Ocean (Tug Clone)	Transport	Medium				LIDAR	
Serva	Transport	Large		Cars (3.31ton)		LIDAR	
Kiva Systems (maybe not for sale)	Transport	1. 2x2.5x1 2. Medium		1. 1000lb 2. 3000lb	1.3m/s	Recharge every hour for 5 minutes, barcodes on the floor with downward camera	
Inspector Bots	Transport	1. 31x26x14” 2. 33x33x16”	1.200lb 2. 240lb	1. 150lb 2. 250lb	1. 3.3 m/s 2. 6.7 m/s	Outdoor, rugged (just a platform)	4 wheel diff