ECE497: Introduction to Mobile Robotics Lecture 1

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Quote of the Week

“Don't tell people how to do things. Tell them what to do and let them surprise you with their results.”

George Patton

What is a robot?

A programmable machine that imitates the actions or appearance of an intelligent creature – usually a human

… a machine able to extract information from its environment and use knowledge about its world to act safely in a meaningful and purposeful manner (Arkin, 1998)

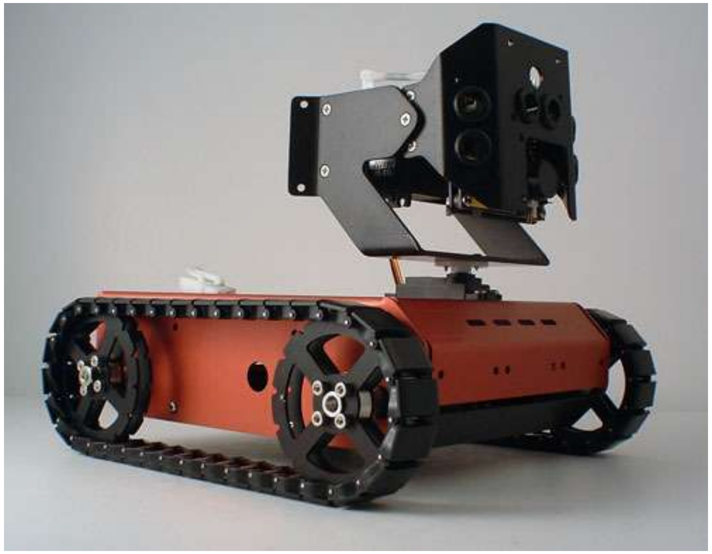
Requirements:

- Must have sensing and perception (i.e. gets information from its environment)
- Must be able to complete different tasks (i.e. locomotion or manipulation)
- Re-programmable for different tasks or actions
- Functions autonomously or interacts with human beings

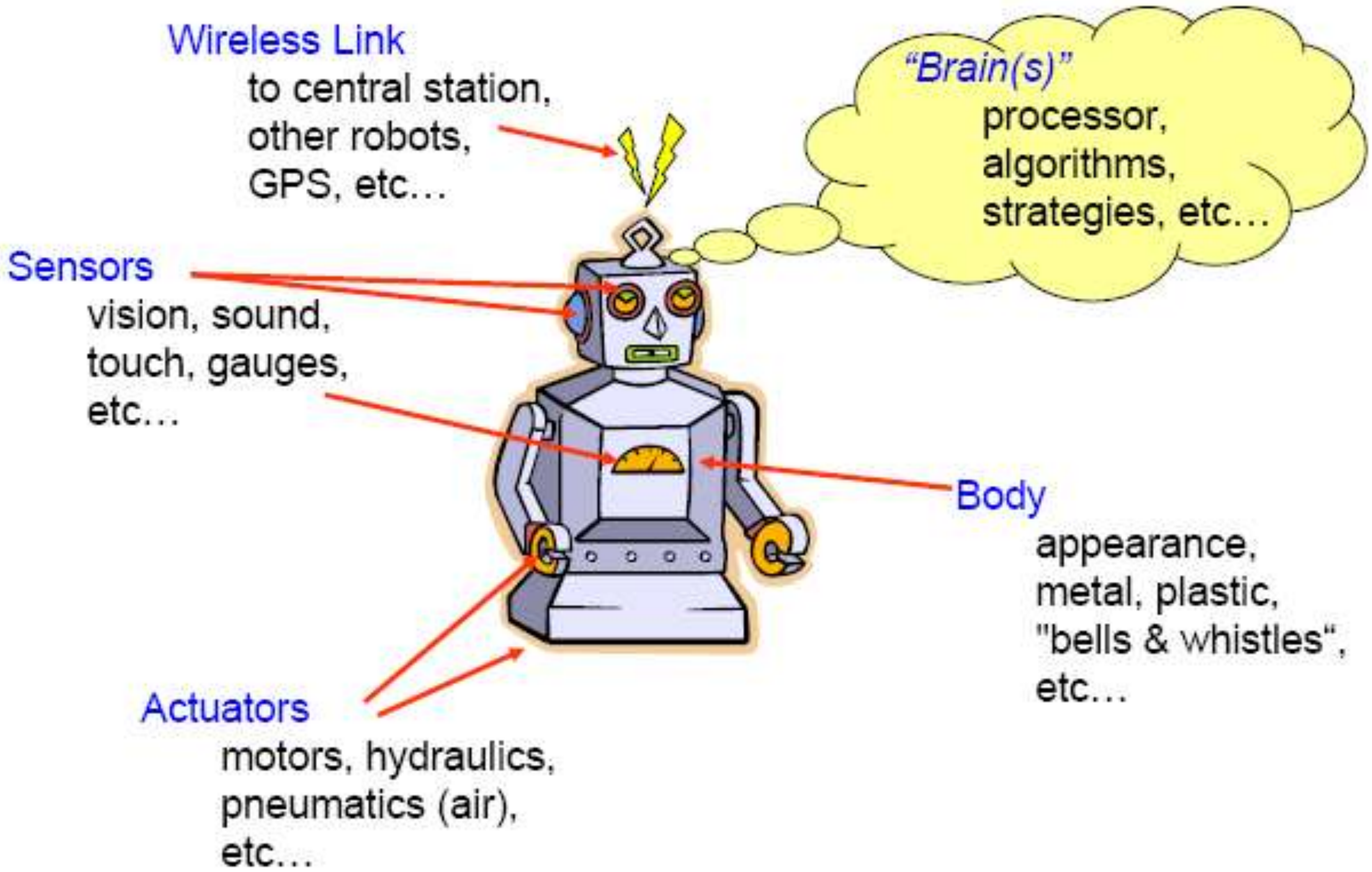
What is Robotics?

The study of robots, autonomous embodied systems interacting with the physical world.

Robotics addresses robot ***perception, interaction*** *and* ***action*** *in the physical world.*



Robot Components



Robot Components, cont.

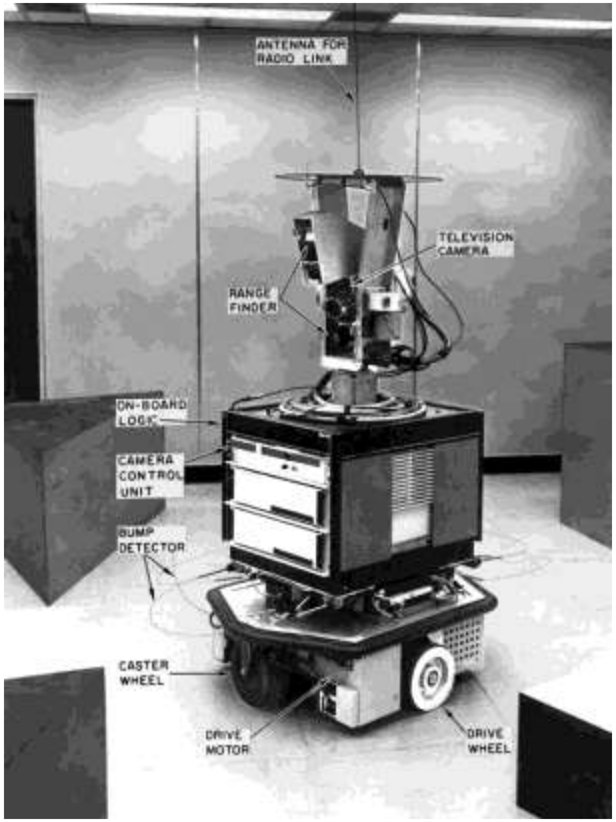
- **Sensors**
  - Used to extract relevant information from the robot's surroundings
- **Effectors and actuators**
  - Used for robot locomotion (movement)
  - Use for robot manipulation
- **Controllers**
  - Used to coordinate information from the sensors with commands to the robot's actuators

Introduction

- Industrial manufacturing (1961)
- Manipulators
- Advantages
  - Great speed
  - Accurate
  - Repetitive tasks
  - Spot welding and painting
- Disadvantage: lack of mobility

Mobile Robot History

- 1970 – Shakey robot (Stanford Research Institute)
- 1st mobile robot to use AI techniques
- controlled by a large computer
- Used spatial data from camera and laser range measurements to recognize objects
- Created a path to the object
- Pushed the objects (blocks) over when found



Various mobile robots

Honda Walkin
g

NASA Nomad

Sony AIBO

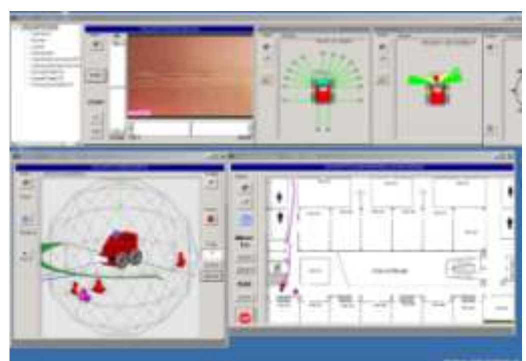
ROV Tiburon Underwater

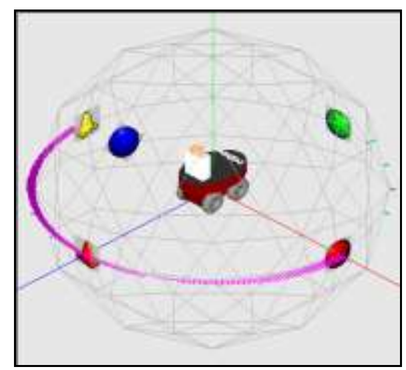
Pioneer

BR700 Cleaning Robot

Human-Robot Interaction

Research and the application of robotics, human-computer interaction, artificial intelligence, interface design, natural language understanding, human factors and cognitive psychology to make effective and efficient interactions between humans and robots.





What is Artificial Intelligence (AI)?

the scientific understanding of the mechanisms underlying thought and intelligent behavior and their embodiment in machines (AAAI)

- Knowledge Representation
- Understanding natural language
- Learning
- Planning and problem solving
- Inference
- Search
- Vision
- How intelligent a robot appears is strongly dependent on **how much** and **how fast** it can sense its environment and apply that information to tasks

Autonomous Mobile Robotics

How can a robot move unsupervised through real-world environments to fulfill its tasks?

Questions to answer:

- Where am I?
- Where am I going?
- How do I get there?

This course will deal with Cognition, Locomotion and Navigation

- Perception
- Localization
- Planning
- Motion generation

Teleoperation vs. Autonomy

In hostile or unsafe environments, human operators can ***teleoperate*** a mobile robot. The human performs localization and cognition, the robot provides motion control. (i.e. MARS Rover, Plustech)

MARS Rover Video

Pulstech Walking Robot Video

Some robots share space with humans and their ***autonomy*** allows the robot to maintain a sense of position and navigate without human intervention

CMU Tour Guide Video

Stanley Video

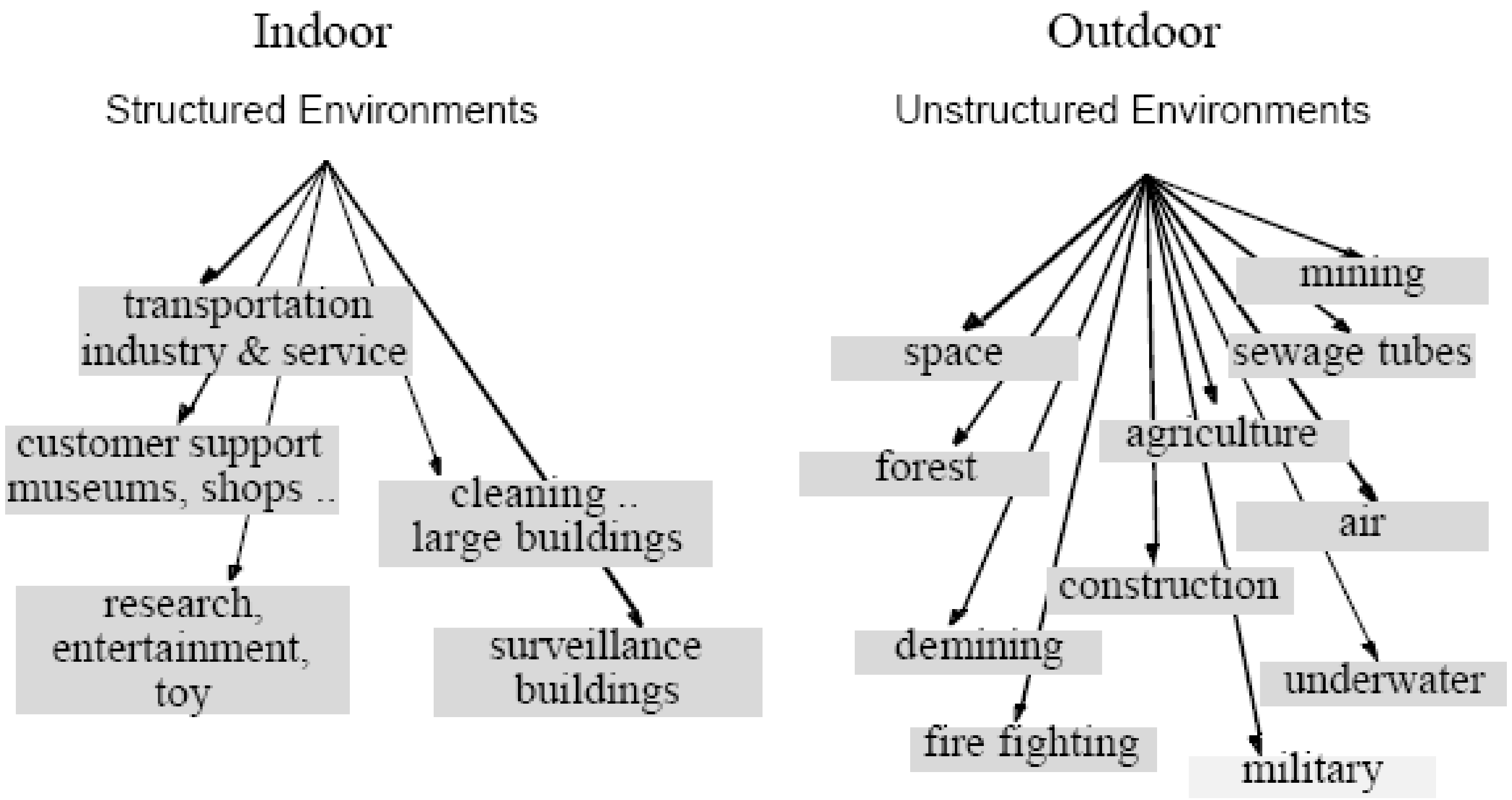
Teleoperation

- the human controls the robot
- the human views the environment through the robot's eyes
- there is no need for artificial intelligence (AI)
- Suited for tasks that are unstructured and not repetitive
- Workspace does not permit industrial manipulators
- Task requires dexterous manipulation, and hand-eye coordination
- Task requires object recognition or situational awareness
- Display technology does not exceed limitations of the communication link (bandwidth or time delays)
- No constraints on the availability of trained personnel

Autonomy

- In semi-autonomous robots, the human may control the robot sometimes
- The robot is viewed as a peer or partner in the workspace with the human
- In supervisory control, the human is involved but routine or safe tasks are handled autonomously by the robot
- In shared control, the human provides the robot with the task but may interrupt the robot with feedback or perceptual inputs or interrupt execution if necessary
- In fully autonomous control, the human initiates the task but does not interact after execution

Applications of Mobile Robots



Autonomous Mobile Robotics

This field is very interdisciplinary because there is a diverse set of challenges in robotics research.

- Locomotion involves mechanism and kinematics, dynamics and control (CHAPTERS 2 and 3)
- Perception involves signal analysis, computer vision and sensor technology (CHAPTERS 4)
- Navigation involves computer algorithms, information theory, probability theory, and information theory (CHAPTERS 5 and 6)

Interdisciplinary robotics

- Mechanical Engineers study robot shape, mechanics, payload limit, materials, walking, climbing, flexing, building
- Electrical and Computer Engineers study sensor/actuator design, wireless communications, board design, computer interfacing)
- Computer scientists study navigation, motion planning, behaviors, machine vision, cooperation and learning strategies
- Cognitive scientists study artificial intelligence, humanoids, neural networks, language processing, learning and memory
- Chemists study nano-sized robots and chemical engineering for motors

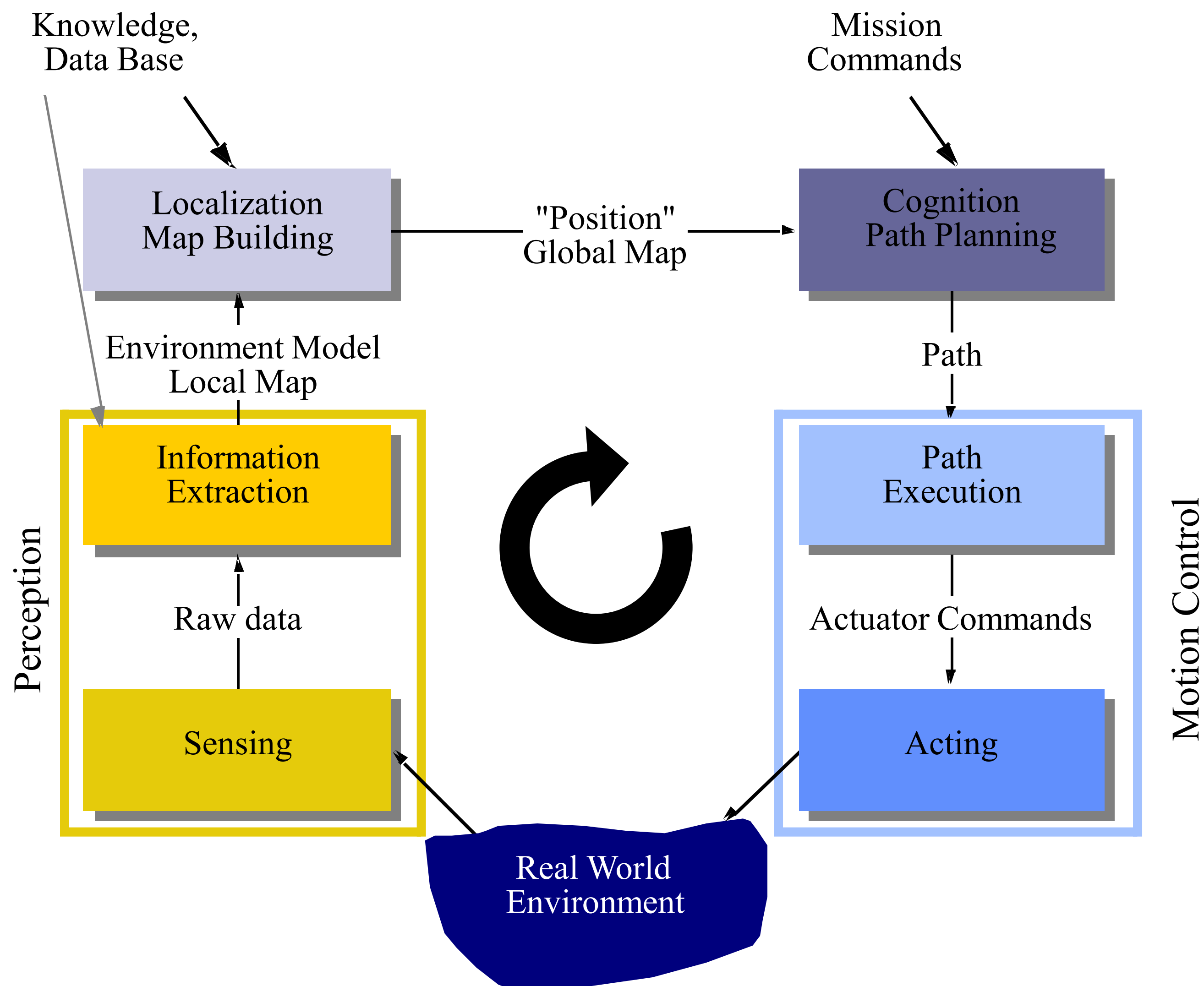
Challenges

- Physical/Mechanical/Electrical issues
  - Sensors are prone to errors and bad readings
  - Sensors have limited range and resolution
  - Sensors are subject to noise and break
  - Sensor input requires lost of processing power
  - Actuators drain batters and are not small or powerful enough
  - Actuators are unpredictable because of noise, wear and tear and mechanical failure
- Knowledge Representation & Retrieval
  - How to represent the real world in a robot’s memory
  - How to extract relevant information from large amounts of sensor data
  - How does the robot adapt to a dynamically changing and unpredictable environment?

Challenges: Uncertainty

- There is an enormous amount of uncertainty in a robot's environment
- The robot's internal model of the environment is approximate
- Algorithms are approximate in order to be real-time
- Robot's have to act on the environment using the insufficient information from sensors and inaccurate internal model
- The robot cannot make decisions with complete certainty

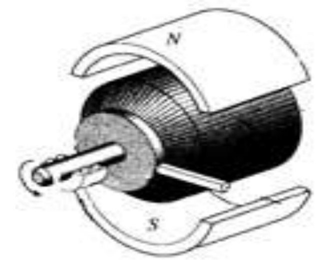
Control scheme for Mobile Robot Systems



Robot Action

- Effectors
  - Devices that have impact on the environment
  - Effectors must match a robot's task
  - Controllers command the effectors to achieve the desired task
  - Wheels, tracks, legs, grippers
- Actuators
  - Mechanisms that allow the effectors to execute an action
  - Pneumatics, electric motors, hydraulics

DC Motors



- DC (direct current) motors
  - Convert electrical energy into mechanical energy
  - Small, cheap, reasonably efficient, easy to use
- How do they work?
  - Electrical current through loops of wires mounted on a rotating shaft
  - When current is flowing, loops of wire generate a magnetic field, which reacts against the magnetic fields of permanent magnets positioned around the wire loops
  - These magnetic fields push against one another and the armature turns

DC Motors: Operating Voltage

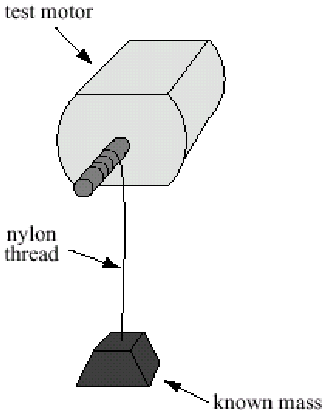
- Motors require electric power in the correct voltage range in order to run (7.2 V for Traxster DC Gearhead Motor)
- Most motors will run fine at lower voltages, though they will be less powerful
- Can operate at higher voltages at expense of operating life

DC Motors: Operating/Stall current

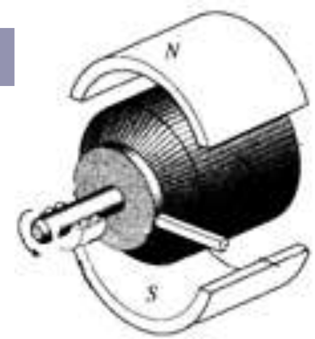
- When provided with a constant voltage, a DC motor draws current proportional to how much work it is doing
- When there is no resistance to motion, the motor draws the least amount of current
- If the resistance becomes very high, the motor stalls and draws the maximum amount of current at its specified voltage (i.e. stall current)

DC Motors: Torque

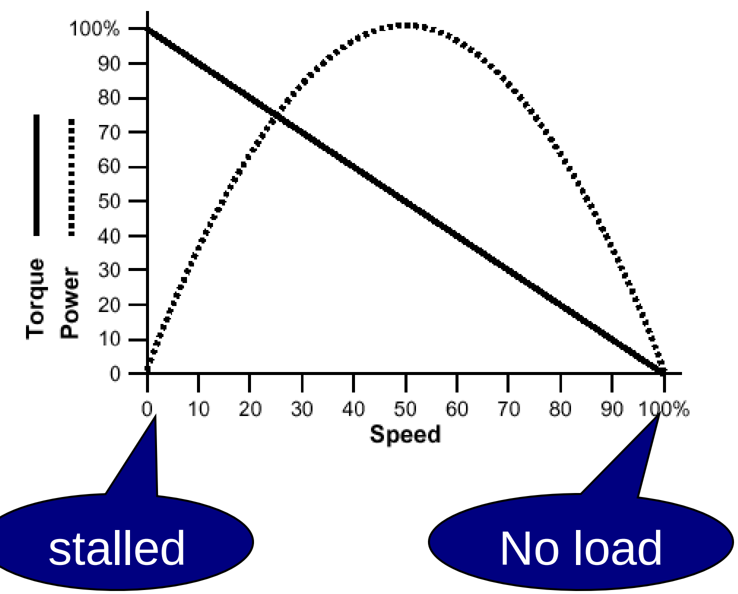
- ***Torque*** is a rotational force that a motor can deliver at a certain distance from the shaft
- The strength of the magnetic field generated in loops of wire is directly **proportional** to amount of current flowing through them and thus the torque produced on motor's shaft
- The more current through a motor, the more torque at the motor's shaft
- ***Stall torque*** is the amount of rotational force produced when the motor is stalled at its recommended operating voltage, thus drawing the maximum stall current (stall torque is 111 oz-in for the Traxster DC motor)
- 111 oz-in torque means the motor can pull weight of 111 oz up through a pulley 1 inch from the shaft



DC Motors: Power

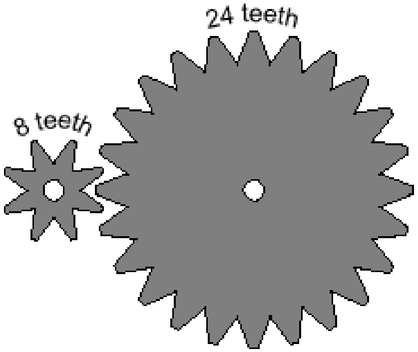


- Motor power is a product of the output shaft's ***rotational velocity*** and ***torque***
- No load on the shaft (Power = 0W)
  - Rotational velocity is at its highest, but the torque is zero
  - The motor is spinning freely (it is not driving any mechanism)
- Motor is stalled (Power = 0 W)
  - It is producing its maximal torque
  - Rotational velocity is zero
- A motor produces the most power in the middle of its performance range.
  - Also at a 50% load the speed would be half and the torque would be half



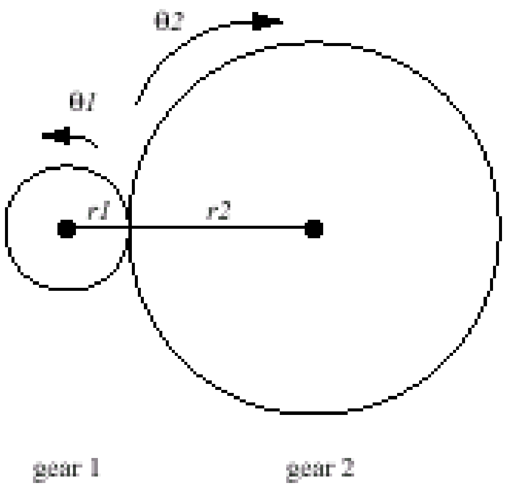
DC Motors: Rotational velocity

- Free spinning speed (175 rpm for Traxster DC motor)
- Motors to drive a robot
  - Need more torque and less speed
- Gears are used to create a tradeoff between high speed and more torque



DC Motors:
Gearing Effect on Speed

- Combining gears has a corresponding effect on speed
- A gear with a small radius has to turn faster to keep up with a larger gear
- Gear ratio = output:input
- (1:54 gear reduction for Traxster)
- For example, the input (driving) gear has 216 teeth and output (driven) gear has 4 teeth
- This produces a 54x increase in speed and decreases the torque by 54



DC Motors: Torque – Speed Tradeoff

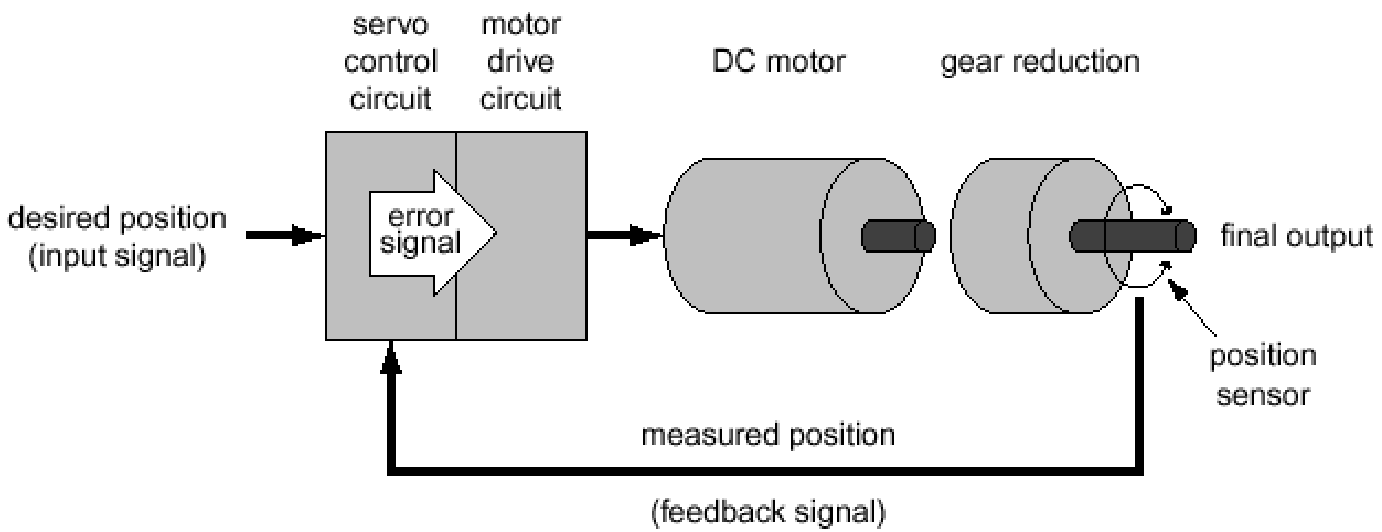
- Increasing the gear radius reduces the speed.
- Decreasing the gear radius increases the speed.
- When a small gear drives a large one, torque is increased and speed is decreased
- Analogously, when a large gear drives a small one, torque is decreased and speed is increased

Servo Motors

- ***Servo motors*** are specialized motors that can move their shaft to a specific position
- **Servo** means to self-regulate its behavior (i.e. measure its own position and compensate for external loads when responding to a control signal)
- Servo motors are built from DC motors by adding
  - Gear reduction
  - A position sensor (encoder) for the motor shaft
  - Electronics that tell the motor how much to turn and in what direction

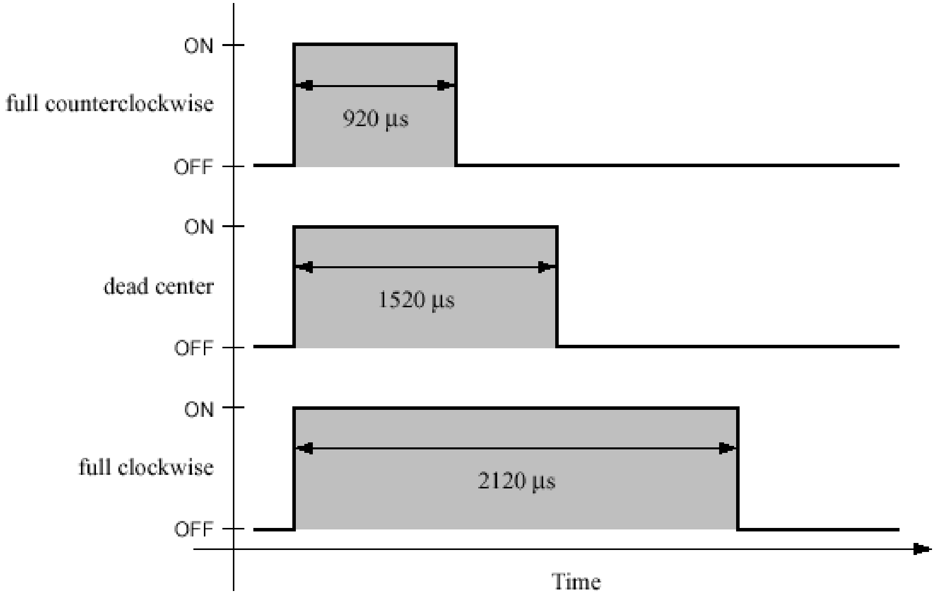
Servo Motors: Operation

- The input to the servo motor is the desired position of the output shaft.
- This signal is compared with a feedback signal indicating the actual position of the shaft (as measured by position sensor).
- An “error signal” is generated that directs the motor drive circuit to power the motor
- The servo’s gear reduction drives the final output.



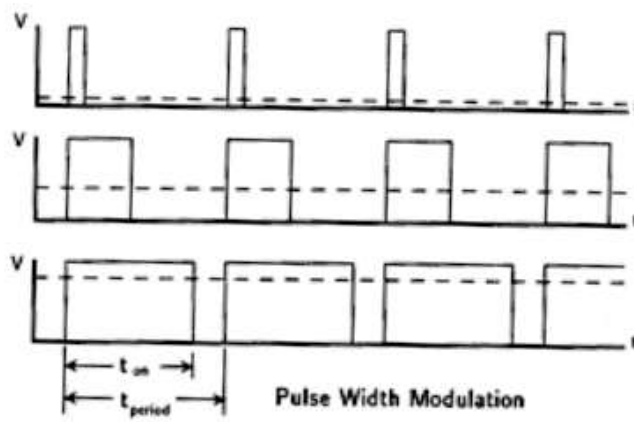
Servo Motors: Control of Speed

- Input to a servo motors is given as an electronic signal, as a series of pulses
  - The length of the pulse is interpreted as the control value: pulse-width modulation
- Width of pulse must be accurate (μs)
  - Otherwise the motor could jitter or go over its mechanical limits
- The duration between pulses is not as important (ms variations)
  - When no pulse arrives the motor stops



Servo Motors: Control of Speed, 2

- Power is not supplied to the motor continuously, it is applied as a square wave at a specific frequency
- Power to the motor is controlled by changing the duty cycle or pulse width of the power signal
- The motor is off for a 0% duty cycle
- The motor is full power at 100% duty cycle
- The frequency of the power signal never changes

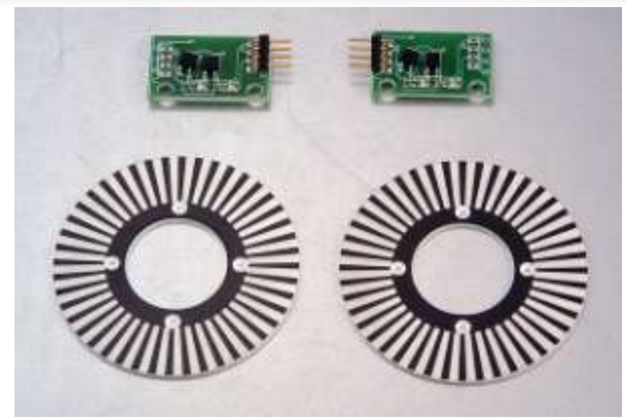


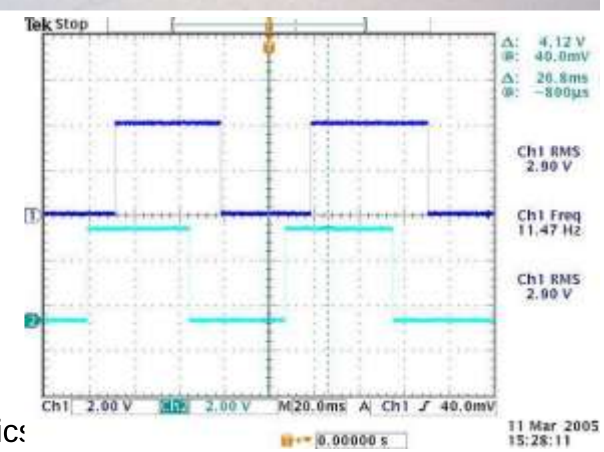
Quadrature Encoder

Quadrature encoding truth table: (NC = No Change, CW = Clockwise, CCW = Counter-Clockwise, Err = Error(Ignore))

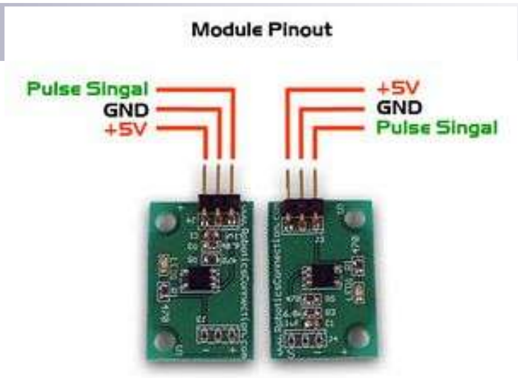
Previous A:B	Current (0:0)	(0:1)	(1:0)	(1:1)
0:0	NC	CW	CCW	Err
0:1	CCW	NC	Err	CW
1:0	CW	Err	NC	CCW
1:1	Err	CCw	CW	NC

- Used to sense a robot's wheel
  - Position (distance traveled)
  - Velocity
  - Rotational direction
- Outputs 2 square waves, 90 degrees out of phase
- The sensor transitions from white to black when the wheel turns
- The module requires +5V and ground and each channel (A, B) outputs +5V when it sees white and 0V when it sees black
- The microcontroller reads to 0-5-0V pulse train to determine how far, how fast and what direction the robot's motors are traveling





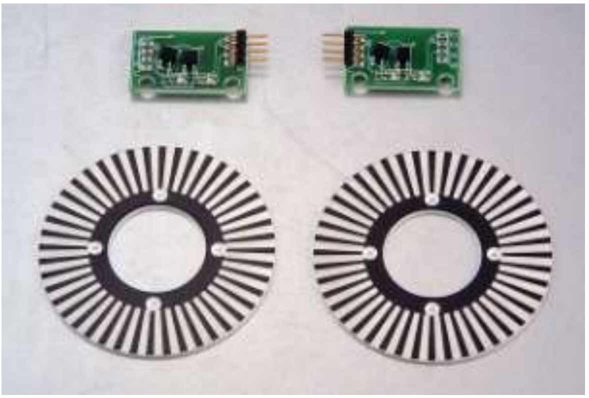
Wheel Encoder

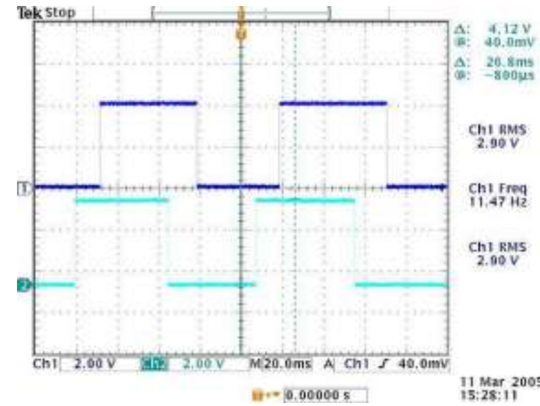


- A ***wheel encoder*** is attached to the shaft of a motor that drives the robot tracks and uses black to white transitions (pulses) to sense robot position or velocity.
- The Traxster wheel encoder has 4 spoke encoder disk on the input shaft

  (216 pulse counts/motor revolution)

Quadrature Encoder, 2





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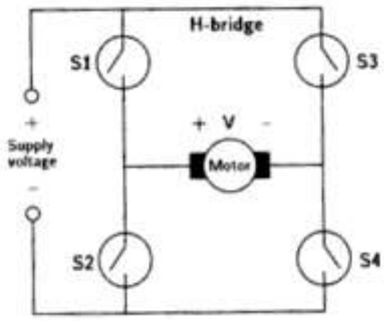
0:0	NC	CW	CCW	Err
0:1	CCW	NC	Err	CW
1:0	CW	Err	NC	CCW
1:1	Err	CCw	CW	NC

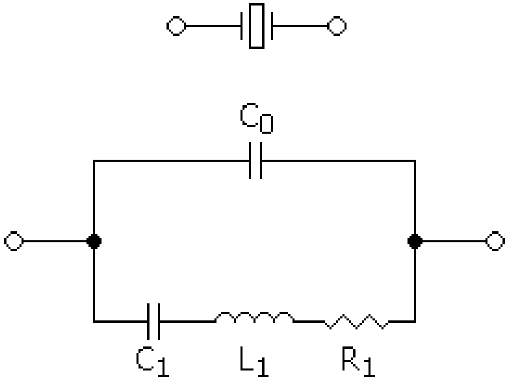
Motors and Microcontrollers

- It is necessary to control speed and direction of a motor by applying voltage and reversing the polarity of the current
- There is not enough current in the controller to drive the motor so it is necessary to use a separate power source.
- The power source is combined with control signals from the controller using some interface circuitry
- This interface circuitry is called an ***H-bridge***
- The H-bridge controls speed by opening and closing switches at different rates to yield an average voltage
- The H-bridge controls the direction of the motor by current direction



Crystal Oscillators

- A *crystal oscillator* is an electronic circuit that uses the mechanical resonance of vibrating quartz crystal to create an electrical signal with a very precise frequency
- Each PIC16F877A microcontroller will have a 10 MHz or 20MHz crystal oscillator



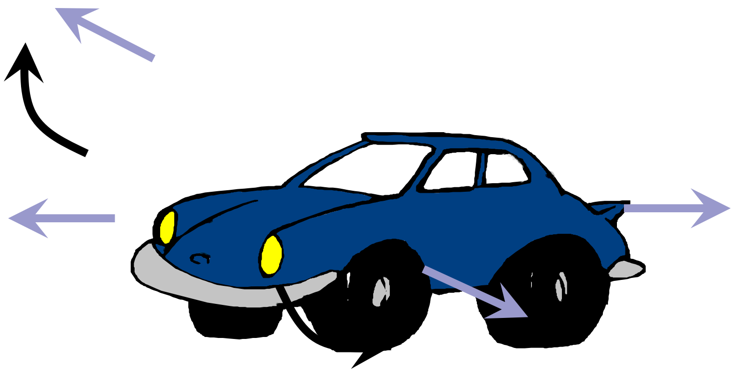
Effectors

- An ***effector*** is any robot device that has an effect on the environment
- wheels, tracks, arms grippers
- The role of the controller is to get the effectors to produce the desired effect on the environment, based on the robot's task

Effectors: Degrees of freedom (DOF)

- ***degrees of freedom*** for an effector are the number of directions in which motion can be made
- Actuators (motors) control a single DOF (left-right, forward-reverse)
- Wheels and tracks have one degree of freedom

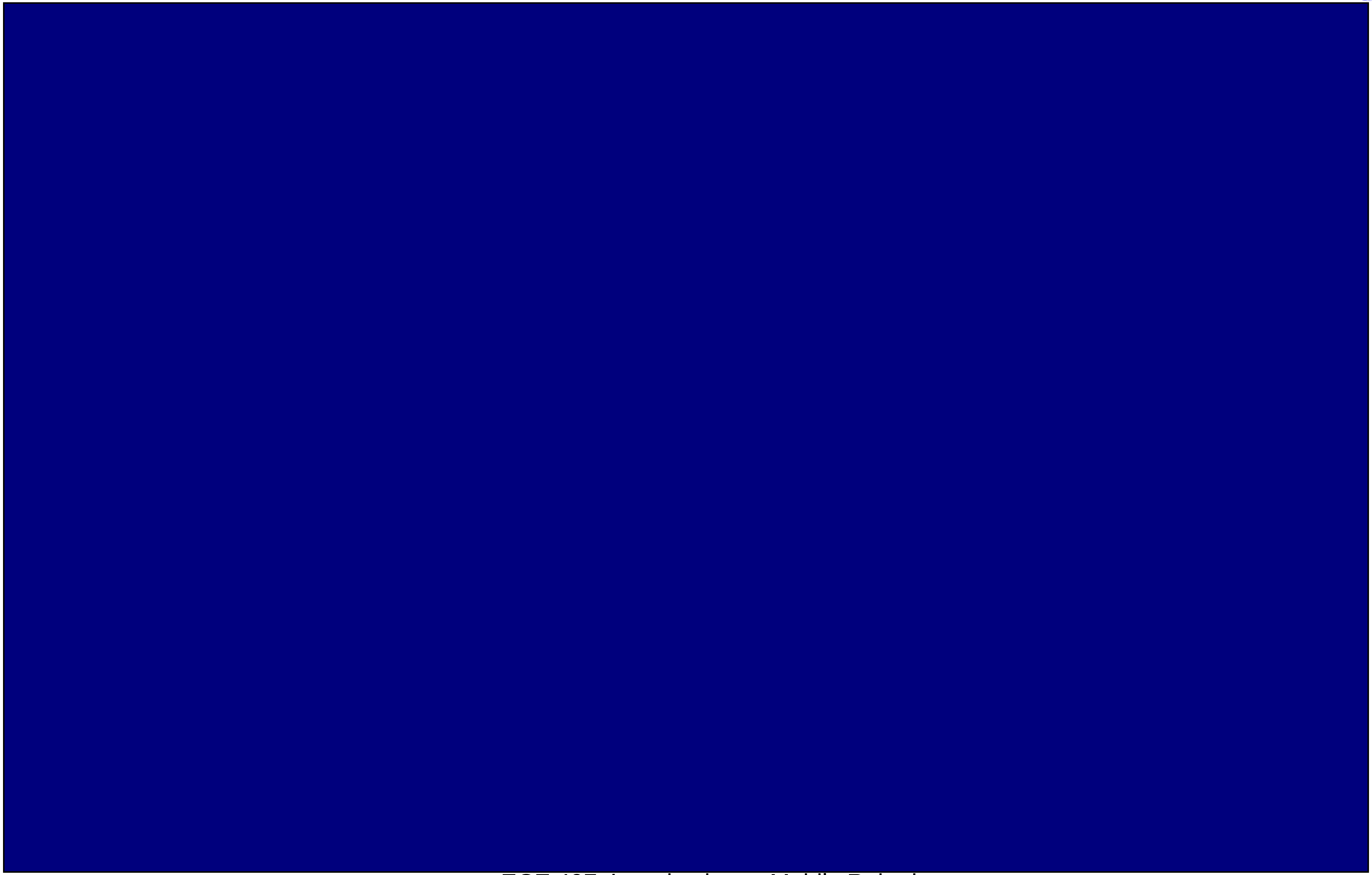
Vehicle:
Degrees of Freedom

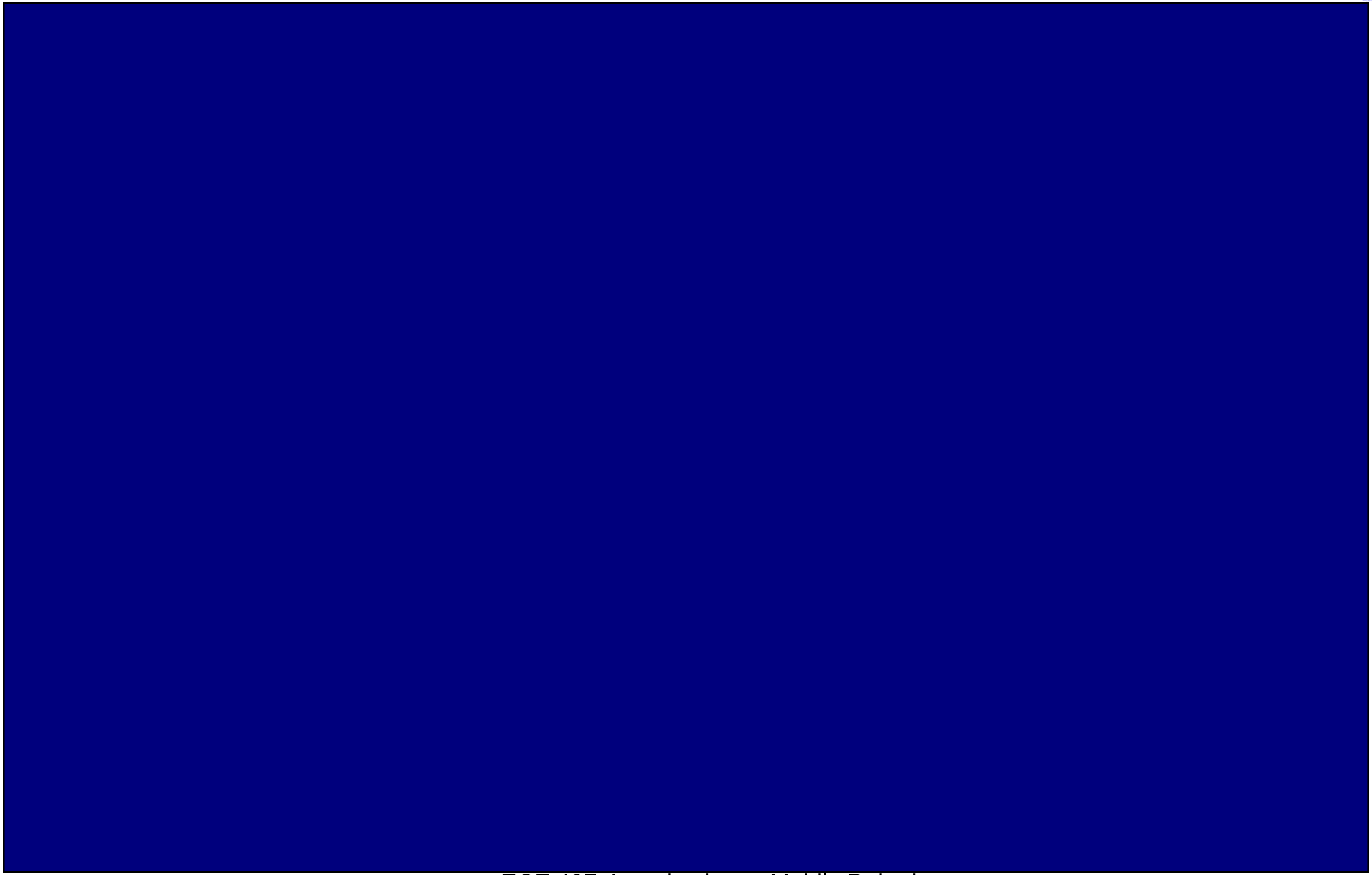


- A car has 3 DOF
  - Translation in two directions
  - Rotation in one direction
- How many of these are controllable?
- Only two can be controlled
  - Forward/reverse direction
  - Rotation through the steering wheel
- Some motions cannot be done
  - Moving sideways
- The two available degrees of freedom can get to any position and orientation in 2D

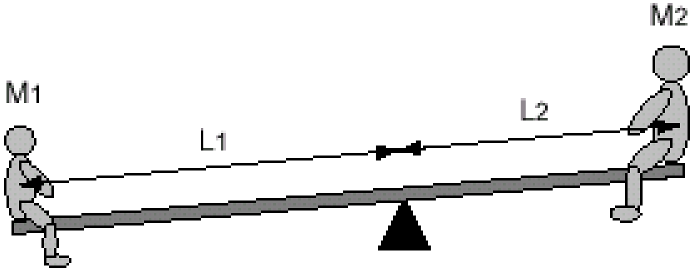
Effectors: Uses

- Locomotion
  - Moving a robot around
- Manipulation
  - Moving objects around
- Effectors for locomotion
  - Legs: walking/crawling/climbing/jumping/hopping
  - Wheels: rolling
  - Arms: swinging/crawling/climbing
  - Flippers: swimming
- Most robots use wheels for locomotion

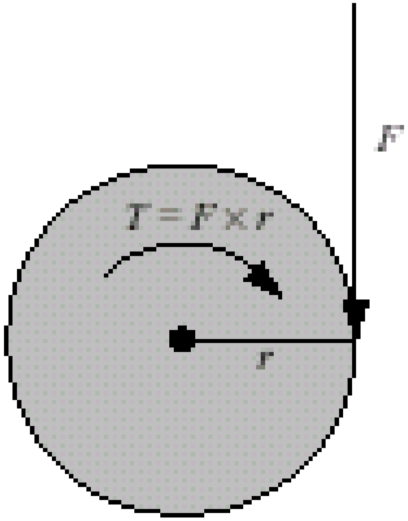




DC Motors: Gearing



- Torques are forces that causes objects to rotate
- Downward Force or Torque = Weight times distance from fulcrum
- Torque: **T = F x r**
- The rotational force generated at the center of a gear is equal to the gear’s radius times the force applied tangential at the circumference

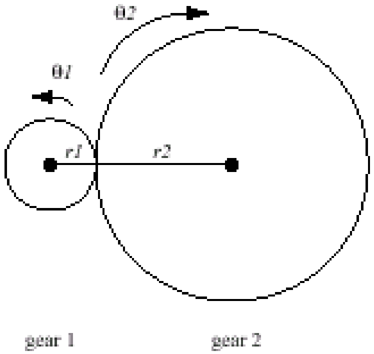


DC Motors: Meshing Gears

- By combining gears with different ratios we can control the amount of force and torque generated
  - Work = force x distance
  - Work = torque x angular movement
- Example: $r_2 = 3r_1$
  - Gear 1 turns three times (1080 degrees) while gear 2 turns only once (360 degrees)

  $T_{output} \times 360 = T_{input} \times 1080$

  $T_{output} = 3\ T_{input} = T_{input} \times r_2/r_1$



DC Motors:
Torque – Gearing Law

$$T_{output} = T_{input} \times r_{output}/r_{input}$$

- The torque generated at the output gear is proportional to the torque on the input gear and the ratio of the two gear's radii
- If the output gear is larger than the input gear (small gear driving a large gear) $\Rightarrow$ torque increases
- If the output gear is smaller than the input gear (large gear driving a small gear) $\Rightarrow$ torque decreases