Intro to controls systems engineering

Kavita Vemuri, 18th March 2019

Contents

- Define a control system
- Describe historical developments leading to modern day control theory
- Describe the basic features and configurations of control systems
- Describe control systems analysis and design objectives
- Describe a control system's design process

Control system

- A control system consists of *subsystems* and *processes* (or *plants)* assembled for the purpose of obtaining a desired *output* with desired *performance*, given a specified *input.*

Examples: Brain as a control system?

Human body or any biological living being as a control system.

https://www.youtube.com/watch?v=jkREF6JZA-I

Human Engineered?

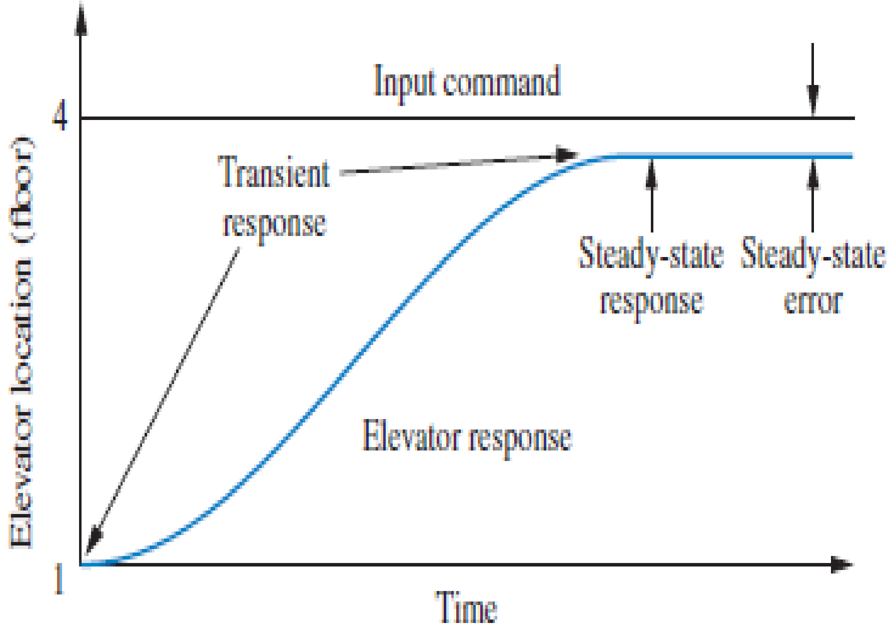
a) https://www.youtube.com/watch?time_continue=2&v=kHBcVlqpvZ8

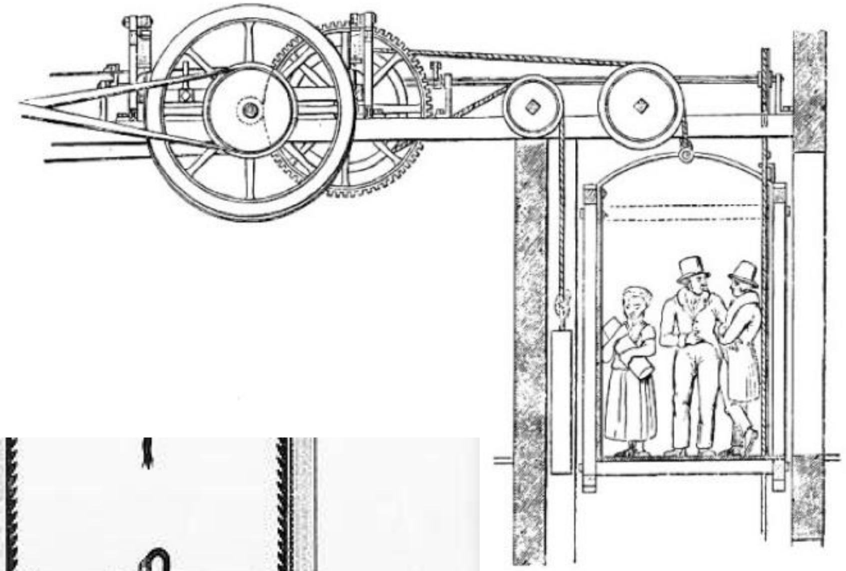
(https://www.youtube.com/watch?v=OPf0YbXqDm0)

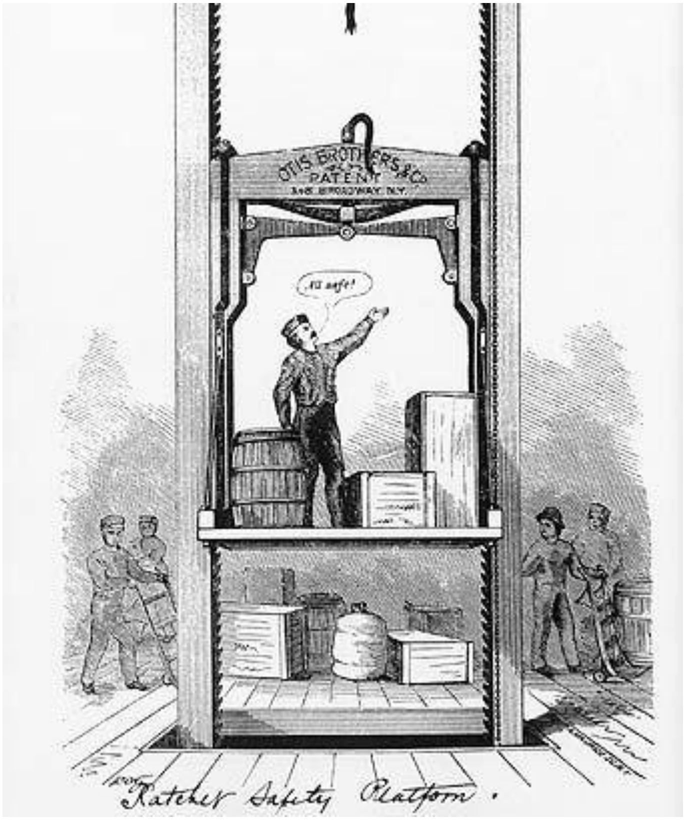
(1:10 to 1:30)

https://www.youtube.com/watch?v=PisoSgwcRVQ

An elevator







Two major measures of performance are :
(1) the transient response and
(2) the steady-state error.

We build control systems for four primary reasons:

1. Power amplification

2. Remote control

3. Convenience of input form

4. Compensation for disturbances

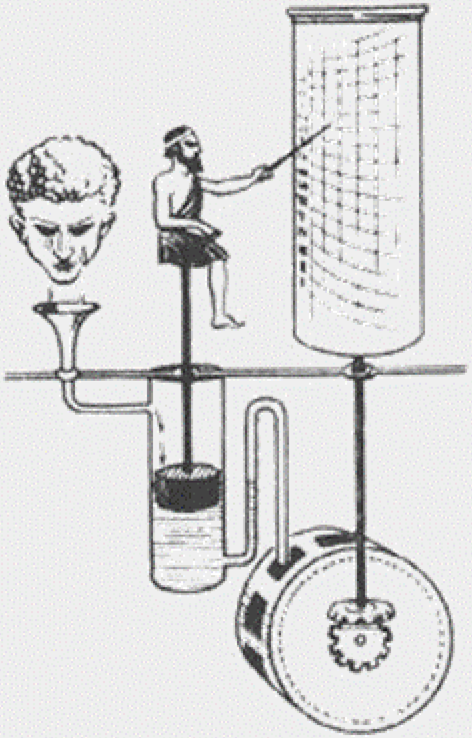
What are the parameters to control in the following:

a) Thermal system?

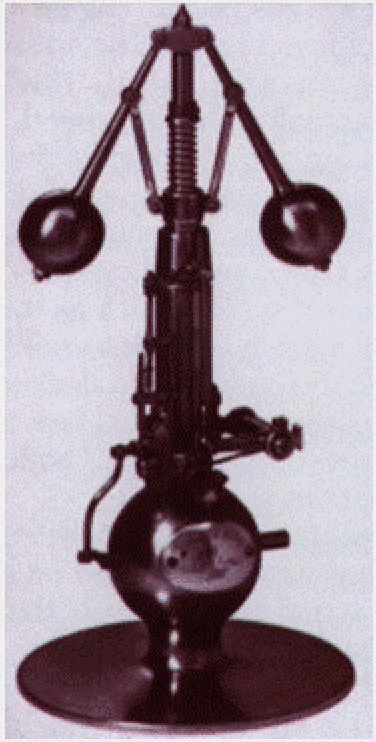
b) Mechanical system?

c) Electrical system?

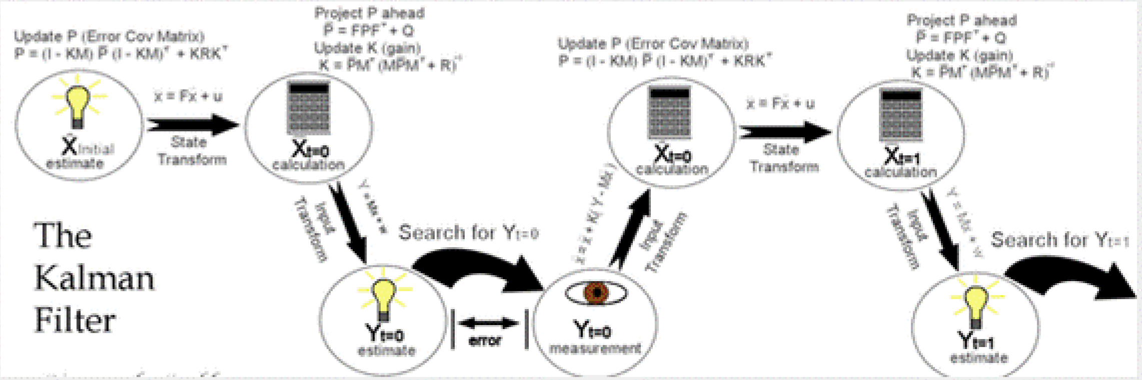
The history of control



Ctesibius's clepsydra (water clock)



Watt's regulator



History

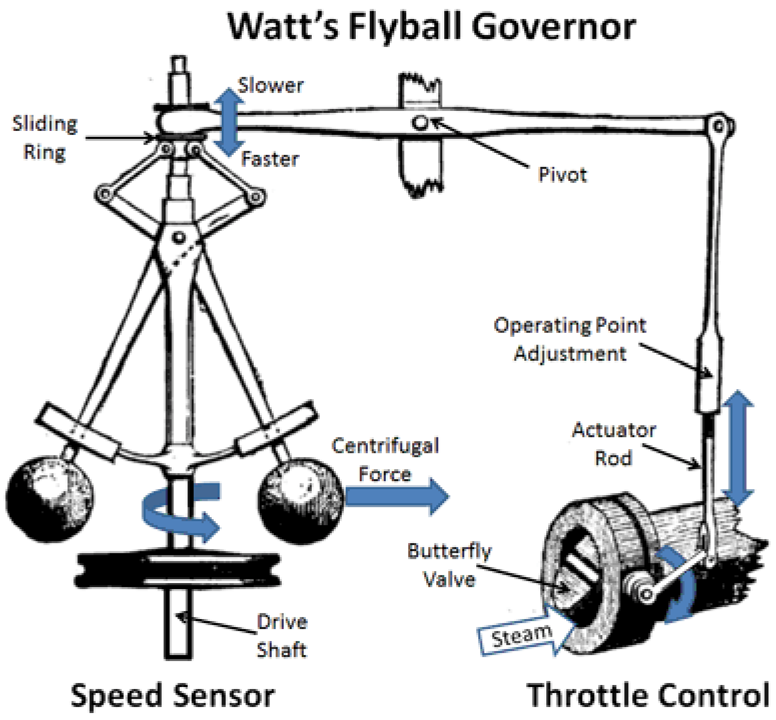
The evolution of control engineering is closely linked to the practical tasks faced by humanity in certain periods of its history, namely the following:

- The ancient Greek and Arabic culture (from ~300 BC to AD ~1200),
- The period of the Industrial Revolution (the 1700s, but trends started in around 1600),
- The emergence of telecommunications (1910–1945)
- The appearance of computers, the start of space research (1957–)

Arabic engineers used various float control devices between AD 800 and 1200. They even discovered two-state (on-off) controllers.

History

- The first industrial control mechanism was Watt’s centrifugal governor which controlled the speed of the steam engine..
- After the Industrial Revolution, the next major step was the definition of how control loops can be described mathematically which made it possible to examine the behaviour of control systems from a mathematical perspective.
- Stability, Stabilization, and Steering: In 1874, Edward John Routh extended Maxwell’s 3^{rd} order system based on differential equations, submitted a paper entitled *A Treatise on the Stability of a Given State of Motion* and won the Adam’s prize.
- During the second half of the 1800s, the development of control systems focused on the steering and stabilizing of ships.
- In 1874, Henry Bessemer, using a gyro to sense a ship’s motion and applying power generated by the ship’s hydraulic system.
- The automatic control systems is attributed to Nicholas Minorsky, year 1922-23, developed a theoretical concept which was applied to the automatic steering of ships that led to what we call today proportional-plus-integral-plus-derivative (PID), or three-mode, controllers.



History

- The invention of the telephone and the application of feedback operational amplifiers for compensating the damping effect during information transfer.
- During WW2 many precision control systems were developed: automated air-traffic control systems, radar antenna calibration systems, the control systems of submarines etc
- The emergence of computers heralded a new era in the development of control systems. Computers are not only used as external devices for easier and more meticulous design, but they are integrated into the control loop in real-time applications.
- The process and the computer controlling it are connected by peripheries, and the manipulating signal is calculated at all sampling times by software and it is fed to the process input. Thus, computers became organic part of the control loop.

History

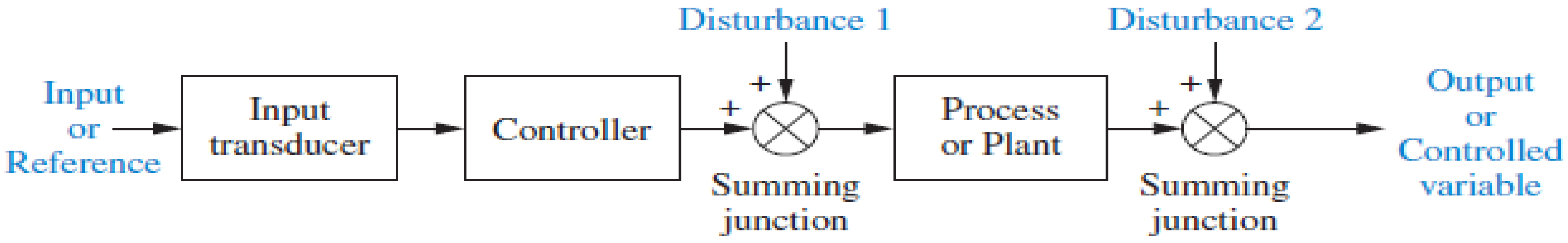
- Industrial robots were designed to perform precision tasks. Mobile robots are programmed to behave intelligently, for example to recognise and avoid obstacles while moving.
- Space research poses another great challenge for control systems. Putting space shuttles and artificial space objects into orbit and ensuring that they reach their destination require highly accurate, adaptive and super safe control systems which capable of learning.

Present…

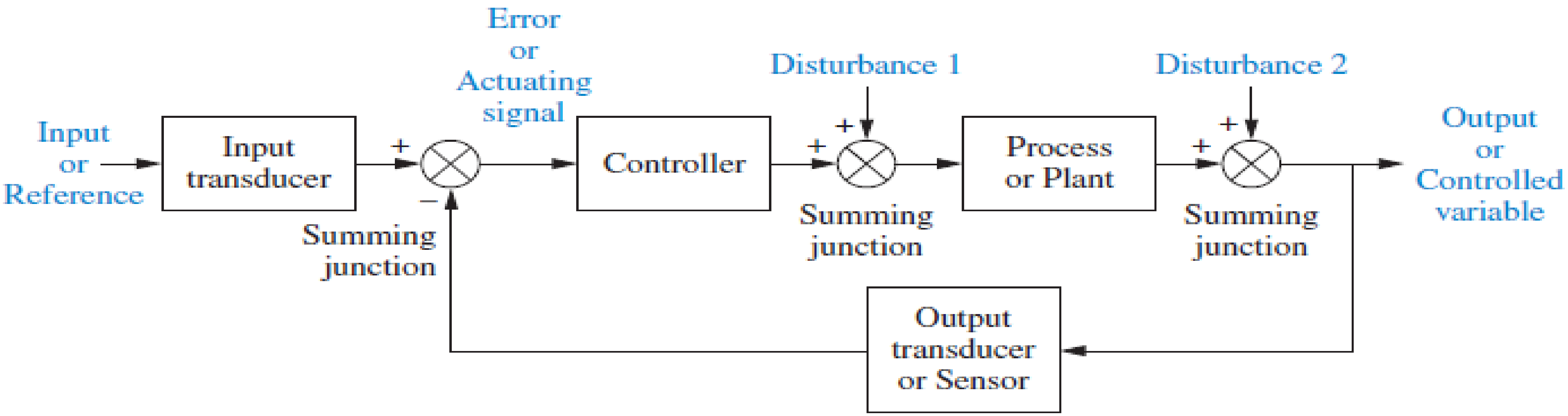
- The emergence of new miniature sensors and manipulators open up new perspectives for control engineering.
- Industrial production processes are now increasingly characterised by distributed control systems (DCS) where several coordinated control systems at different locations ensure high production levels.
- These systems communicate with and instruct each other, and are capable of carrying out coordinated tasks. The hardware and software enabling all this are already available (PLCs, profibus, TCP/IP, industrial network protocols, etc).

Control theory deals with the structure, analysis and synthesis of control systems.

configurations of control systems



(a)



Example : Toasters are open-loop systems

(b)

Antenna positioning

Analysis and Design Objectives

- *Analysis* is the process by which a system’s performance is determined.
- *Design* is the process by which a system’s performance is created or changed

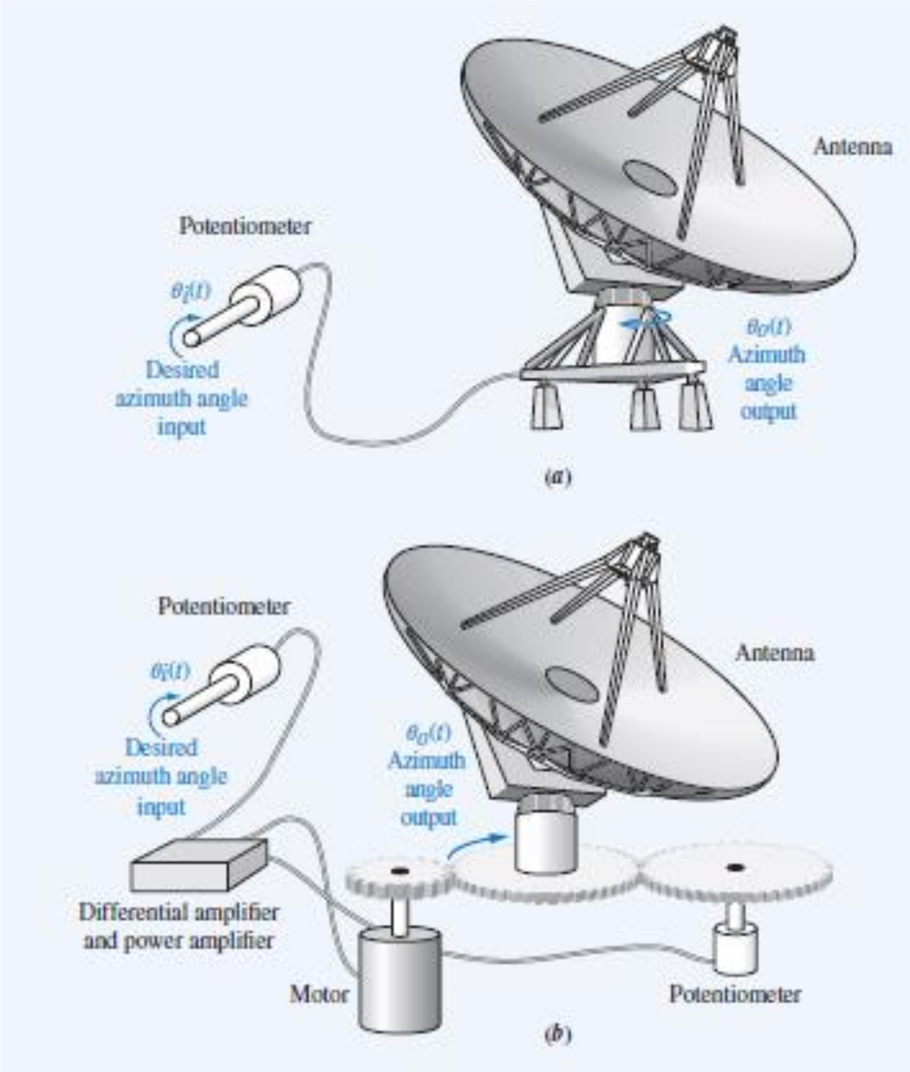
For Stability in a linear system:

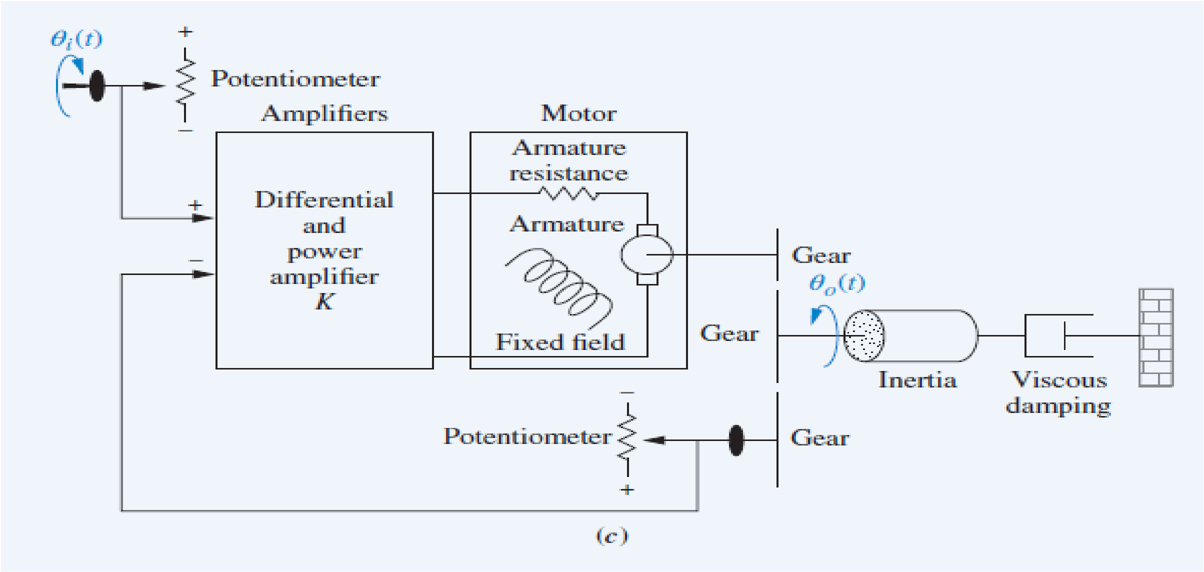
Total response = Natural response + Forced response

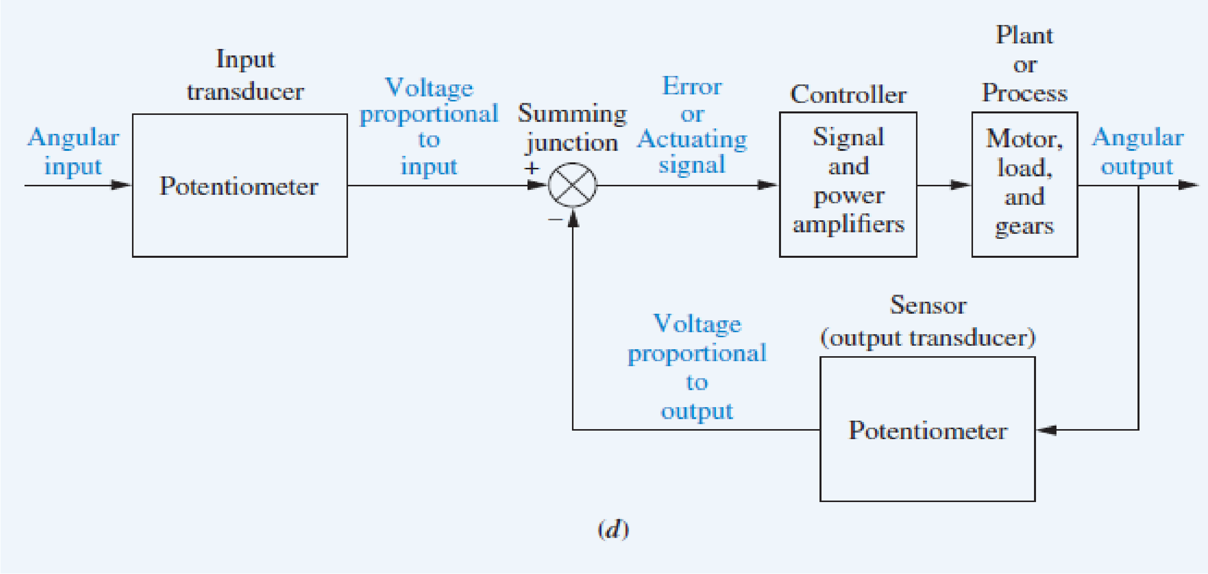
For any control system, the Natural response should a) eventually reach zero, thus leaving only the forced response or b) oscillate

Example: An antenna commanded to point to a target would rotate, line up with the target, but then begin to oscillate about the target with *growing* oscillations and *increasing* velocity until the motor or amplifiers reached their output limits or until the antenna was damaged structurally

Case Study - Antenna







Design objectives and the system’s performance revolve around the transient response, the steady-state error, and stability

Class

- https://www.youtube.com/watch?v=p927NZHvyLY

Class exercise

List the responses, input and the control systems

Stability of a system

- Total response = natural response + forced response
- Natural response describes the way the system dissipates or acquires energy independent of the input signal
- Forced response is dependent on the input.
- For a control system to be useful, the natural response must

(1) eventually approach zero, thus leaving only the forced response,

(2) oscillate.

When the oscillation increases beyond the forced response, instability sets in.

The Role of Control Theory

- **1.** Stability and stability margins of closed-loop systems.
- **2.** How fast and smooth the error between the output and the set point is driven to zero.
- **3.** How well the control system handles unexpected external disturbances, sensor noises, and internal dynamic changes.

Instability

- Mechanical vibrations in aircraft
- Elevators – vibrations that can result in snapping the cables.

Example- automobile

Main Parameters for an Automobile

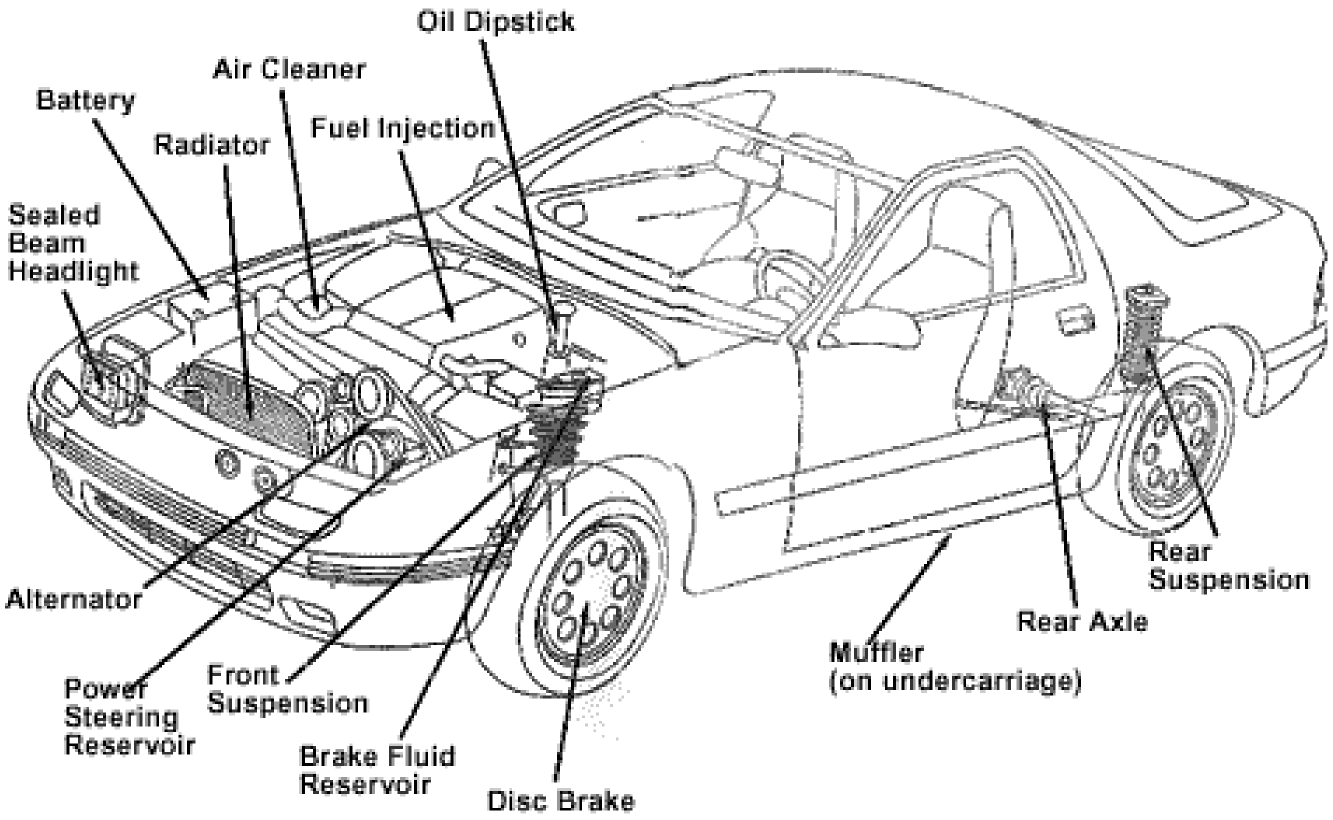
Main: Speed, Efficiency, life, accuracy and noise

Dependent parameters: size, shape, mass of the product.

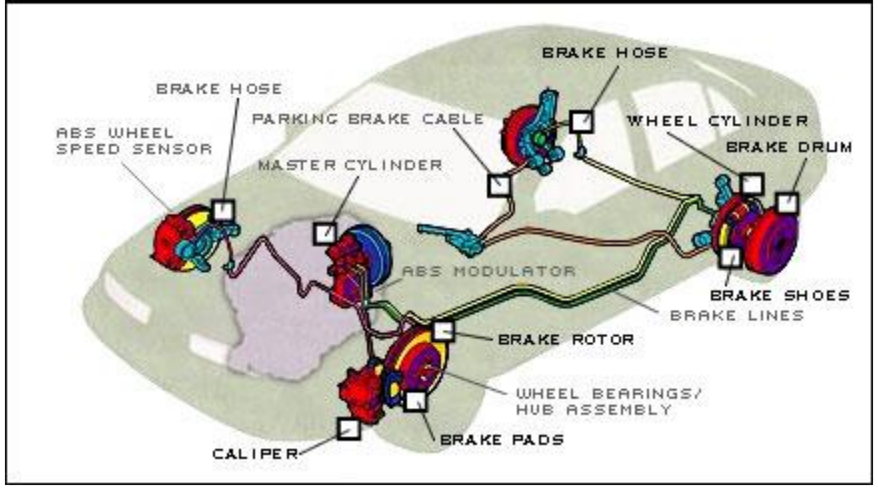
supporting parameters: Acceleration, energy consumption, aerodynamic drag, noise, aesthetics

External Parts of a Car - Overview

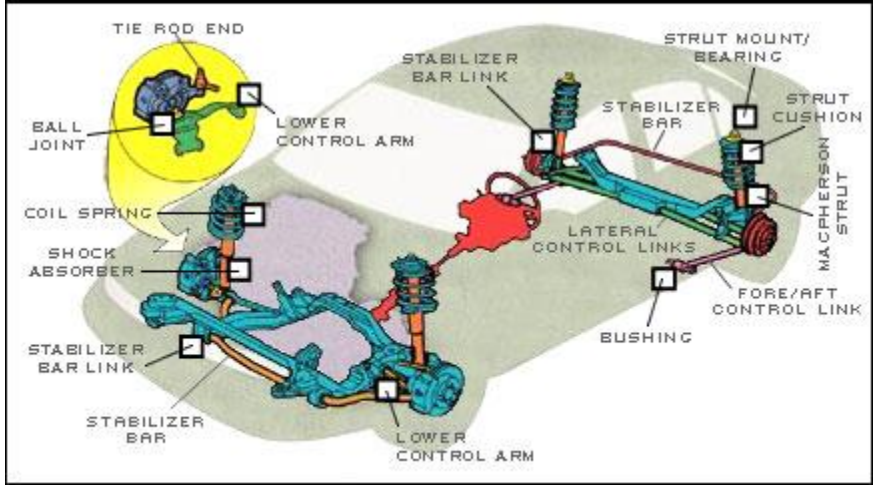
Main internal parts



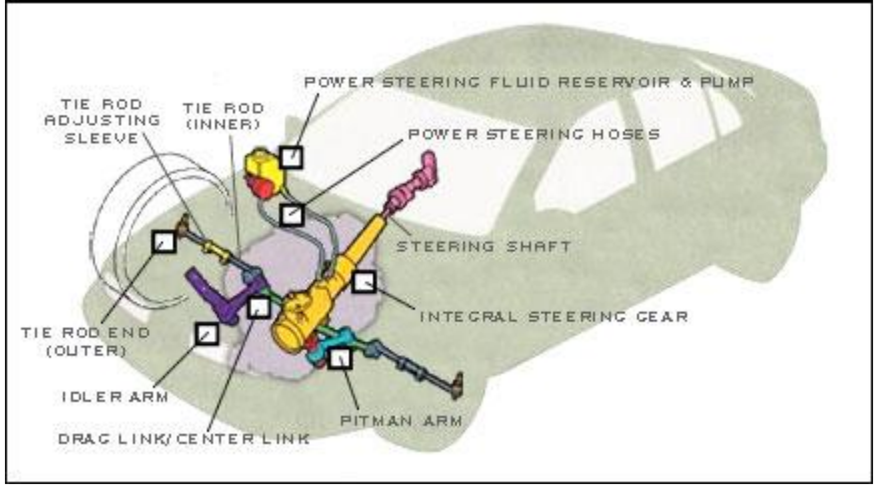
BRAKE SYSTEM



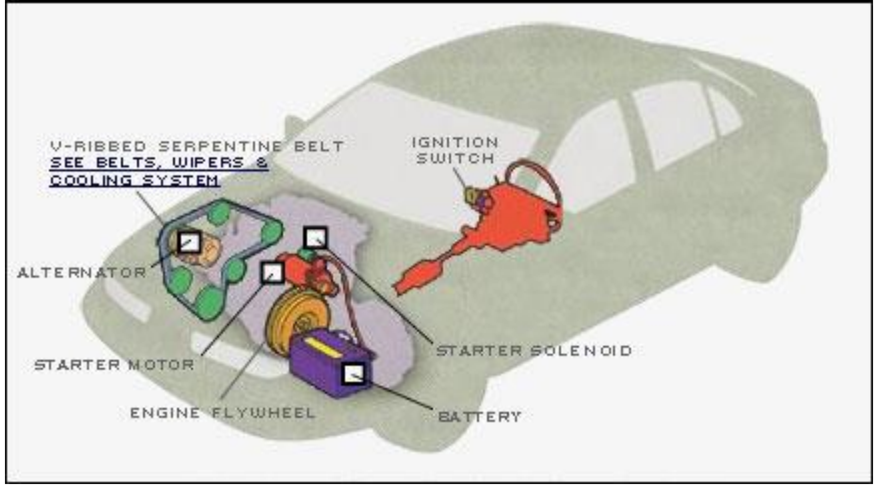
RIDE & HANDLING SYSTEM



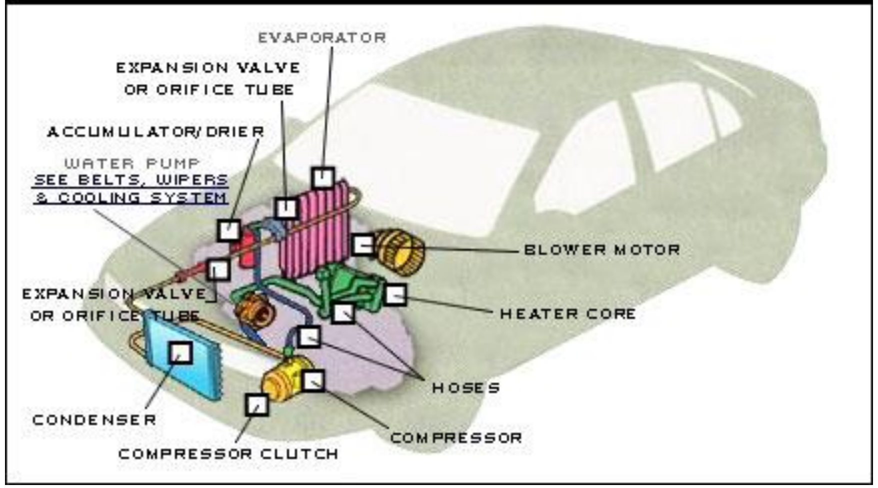
STEERING SYSTEM



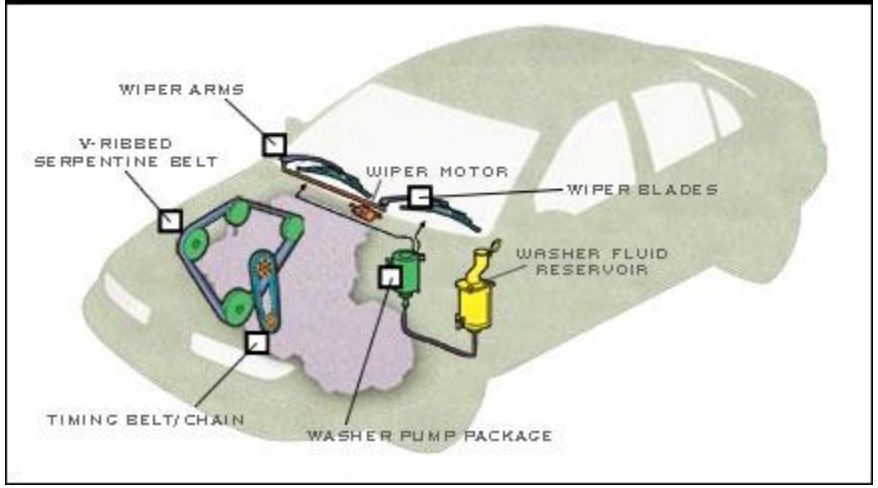
STARTING & CHARGING SYSTEM



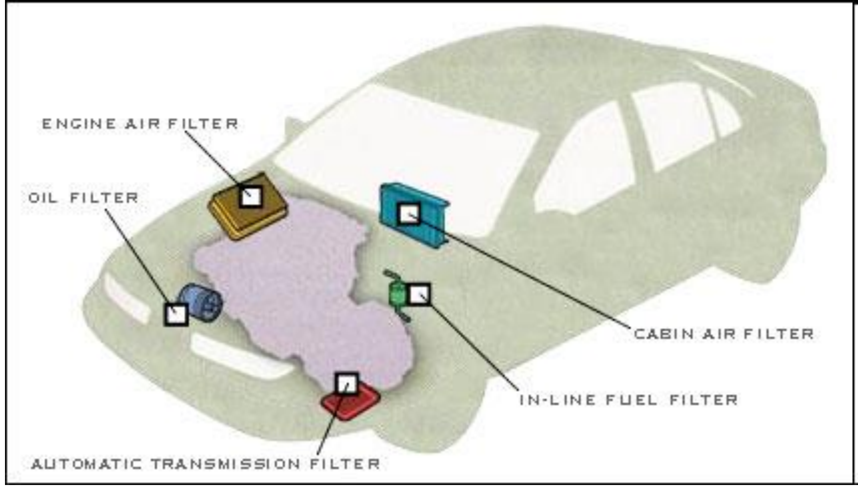
HEATING & AIR CONDITIONING SYSTEM



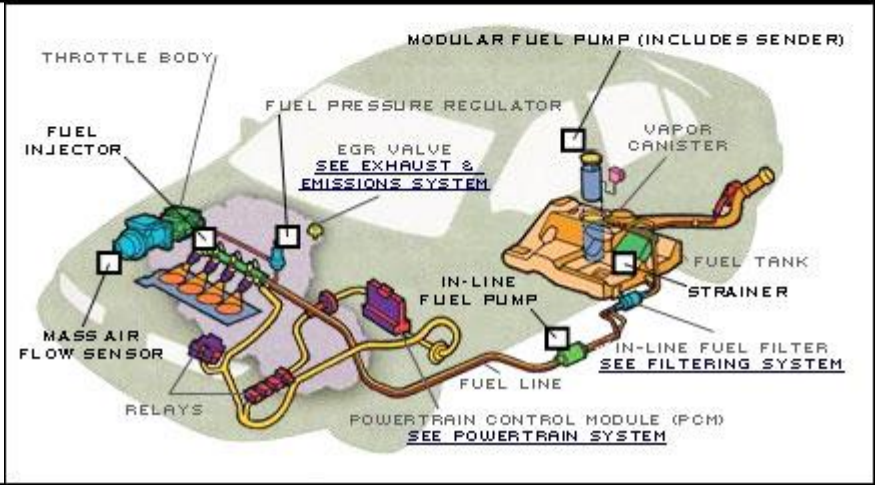
BELTS, WIPERS & COOLING SYSTEM



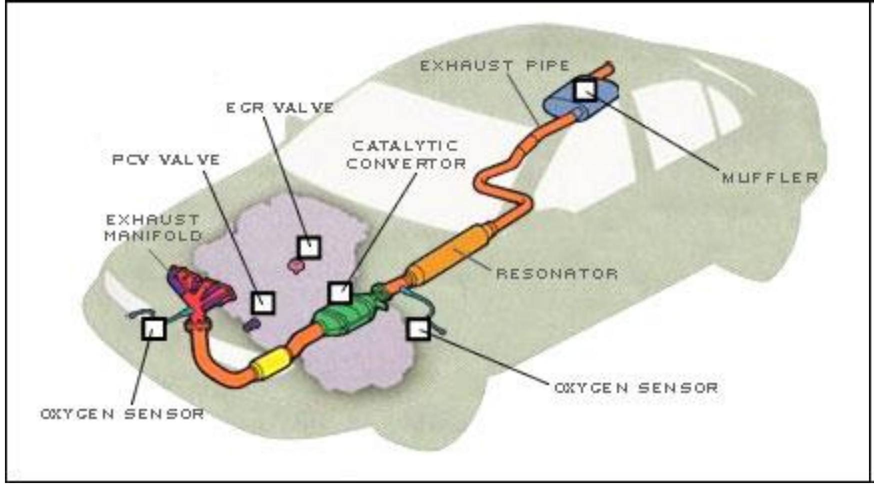
FILTERING SYSTEM



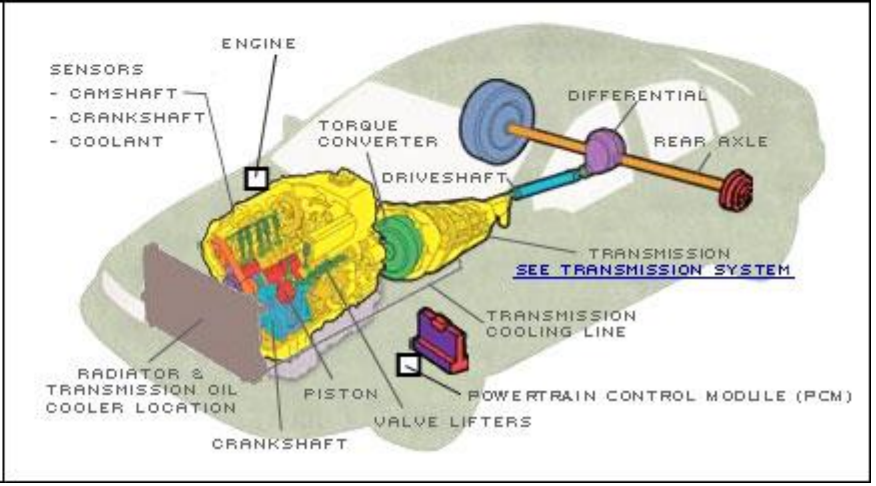
FUEL & ENGINE MANAGEMENT SYSTEM



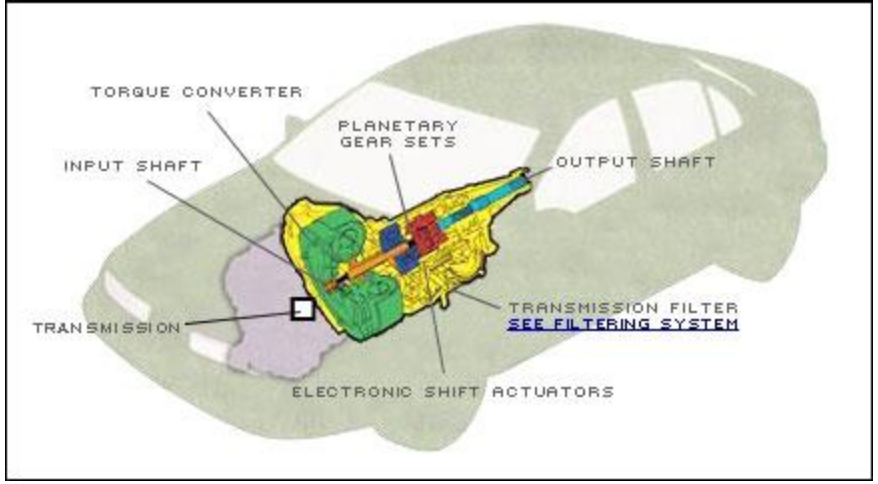
EXHAUST & EMISSIONS SYSTEM



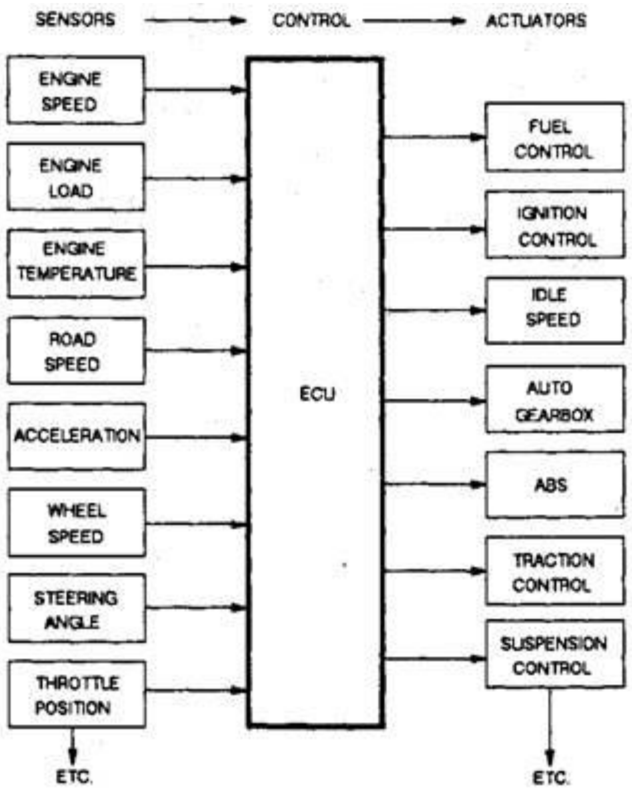
POWERTRAIN SYSTEM



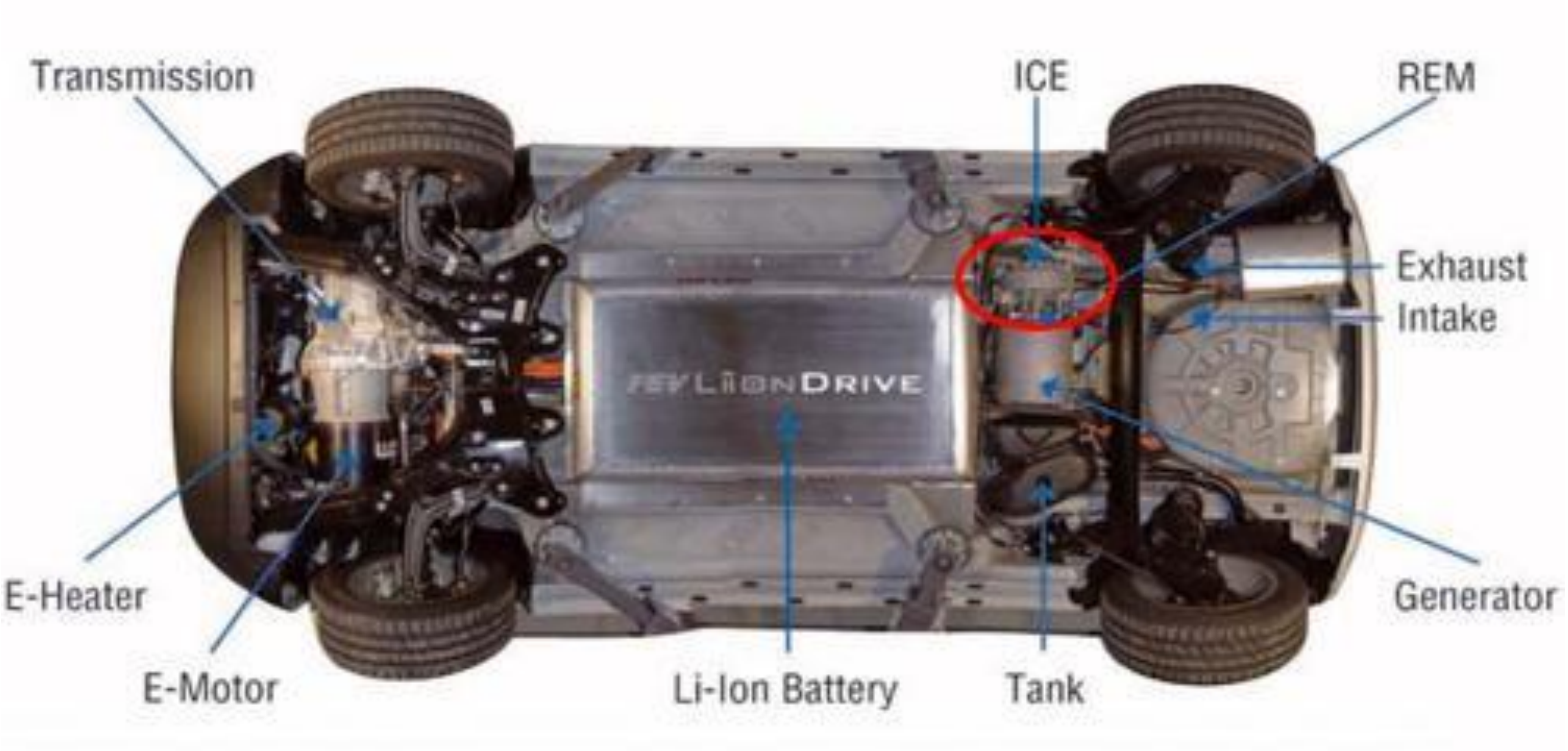
TRANSMISSION SYSTEM



ECU’s and more

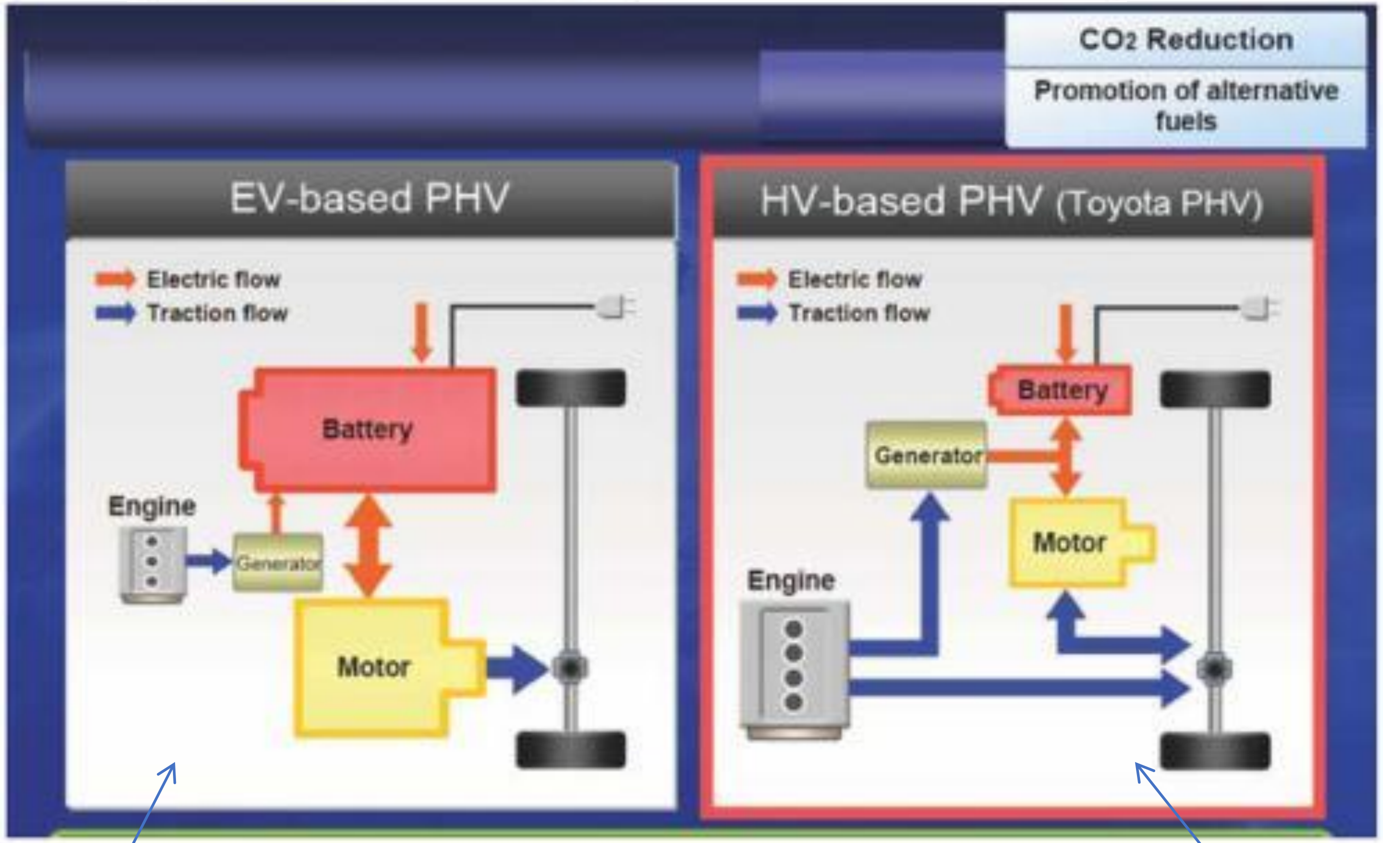


Hybrid



Transmission
ICE
REM
Exhaust
Intake
LiionDrive
E-Heater
E-Motor
Li-Ion Battery
Tank
Generator

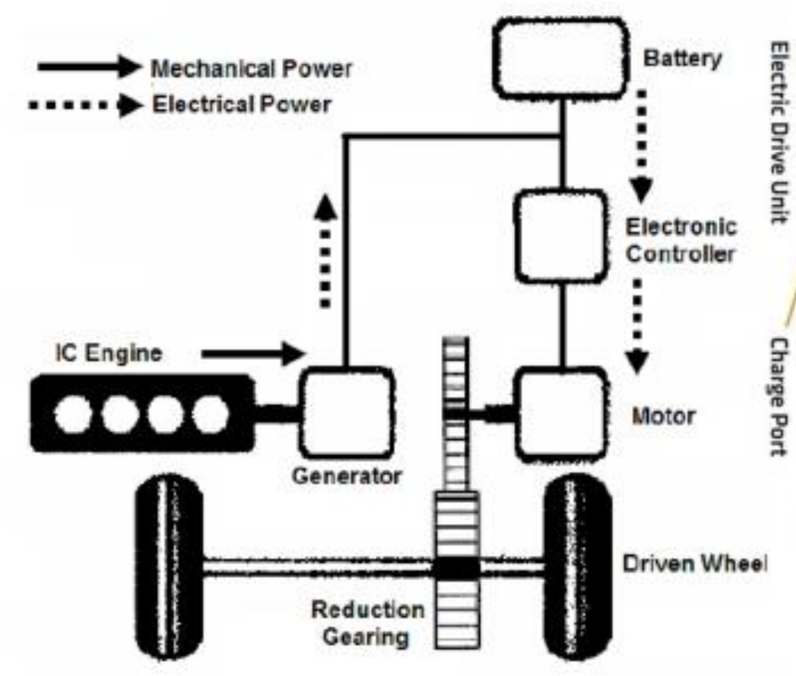
Chevy Volt Vs Toyota Prius



Series Architecture

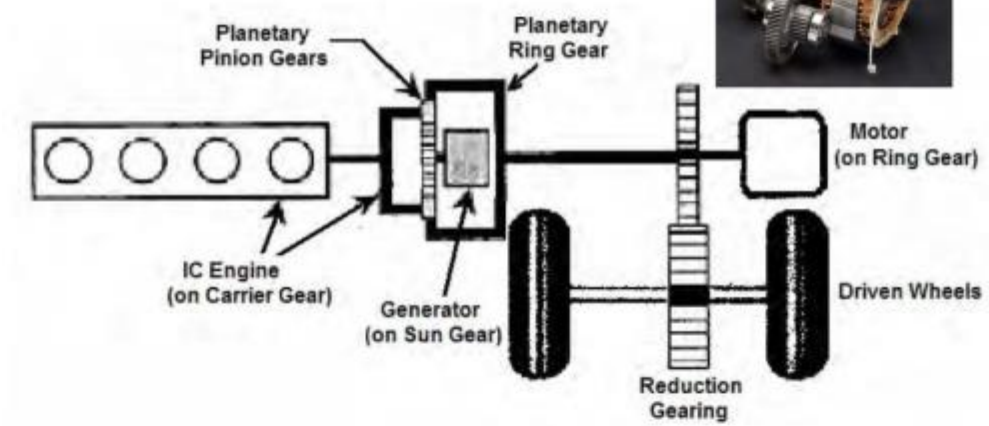
Parallel & Series Architecture

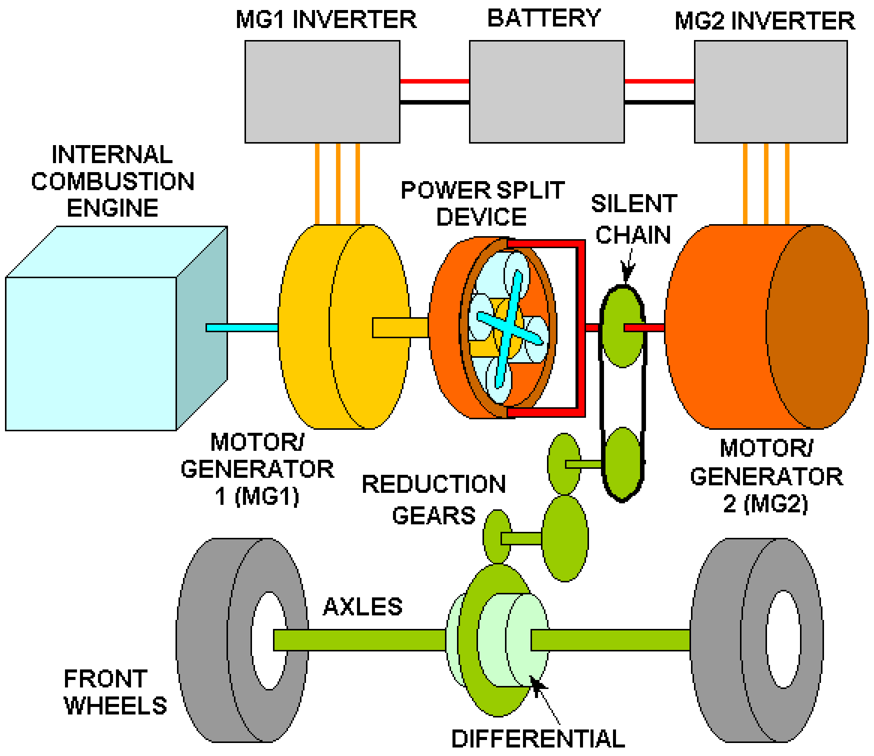
GM Volt

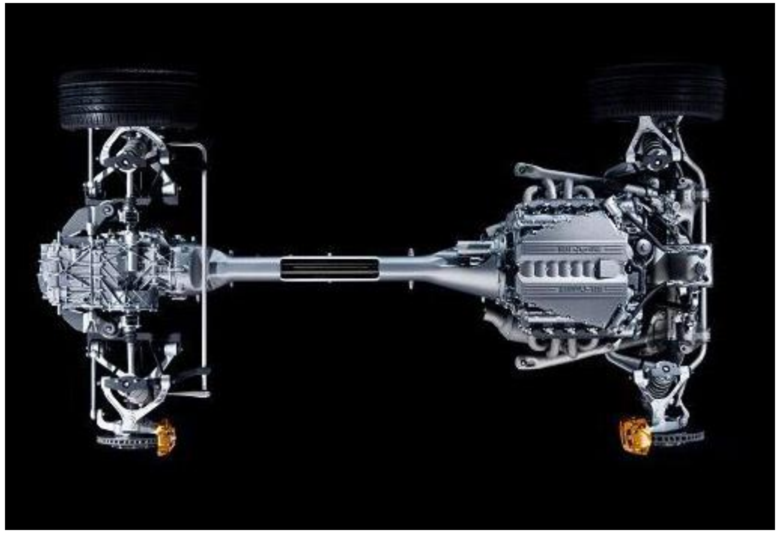


Toyota

Toyota Hybrid-Synergy Drive II (THS-II) – Power-Split




MG1 INVERTER
BATTERY
MG2 INVERTER
INTERNAL COMBUSTION ENGINE
POWER SPLIT DEVICE
SILENT CHAIN
MOTOR/ GENERATOR 1 (MG1)
REDUCTION GEARS
MOTOR/ GENERATOR 2 (MG2)
AXLES
FRONT WHEELS
DIFFERENTIAL



Toyota Pius

AWD layout

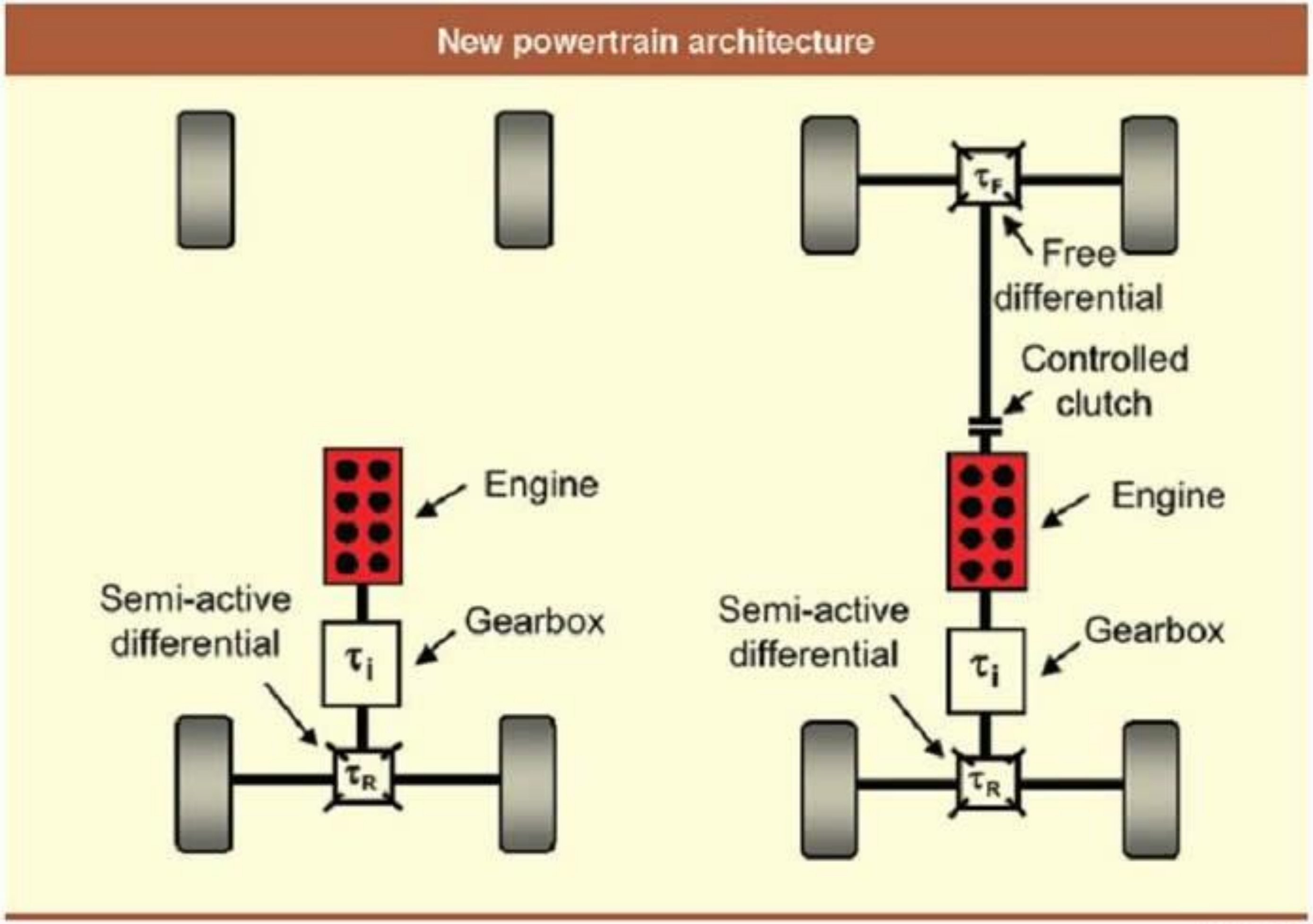
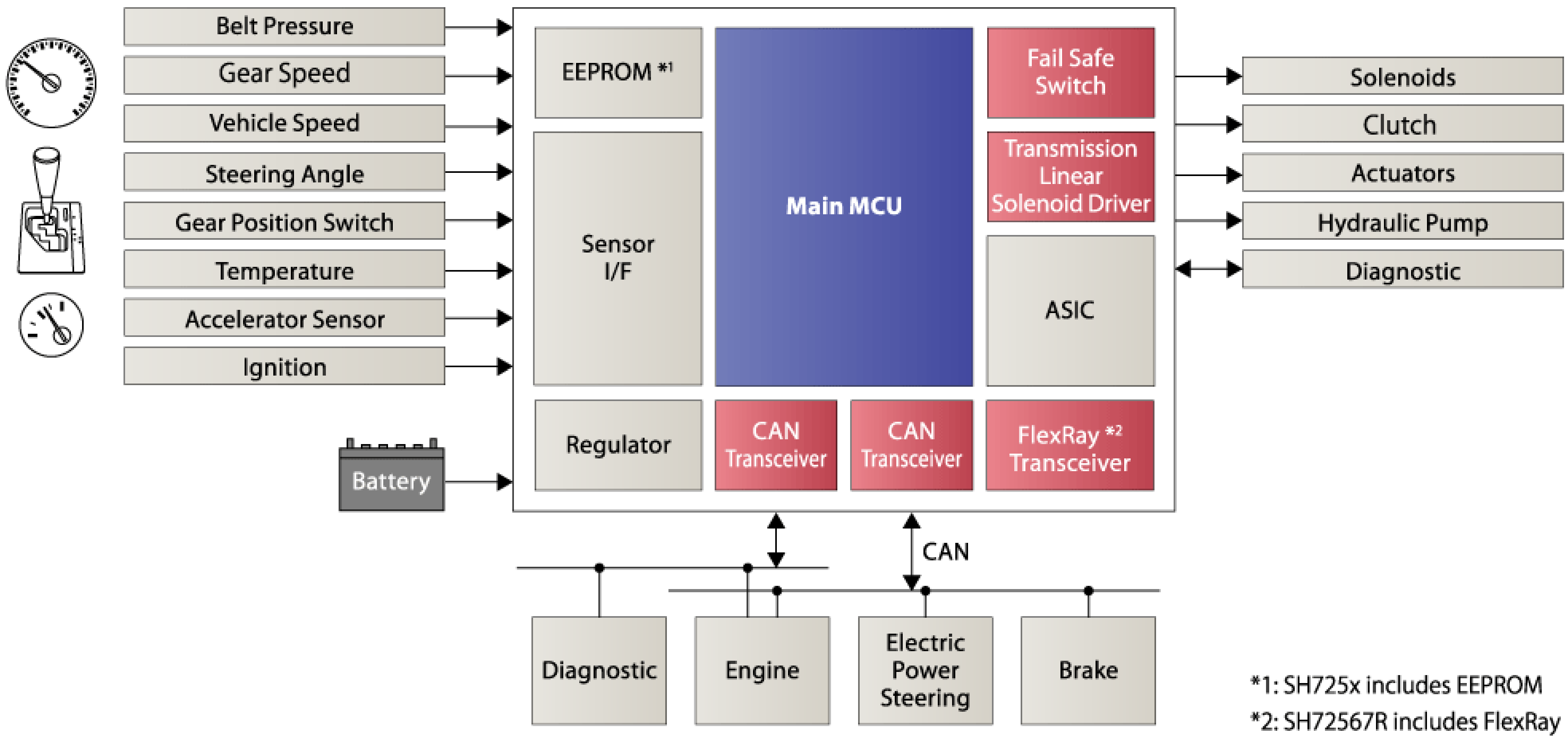


Figure 1

Transmission Control System



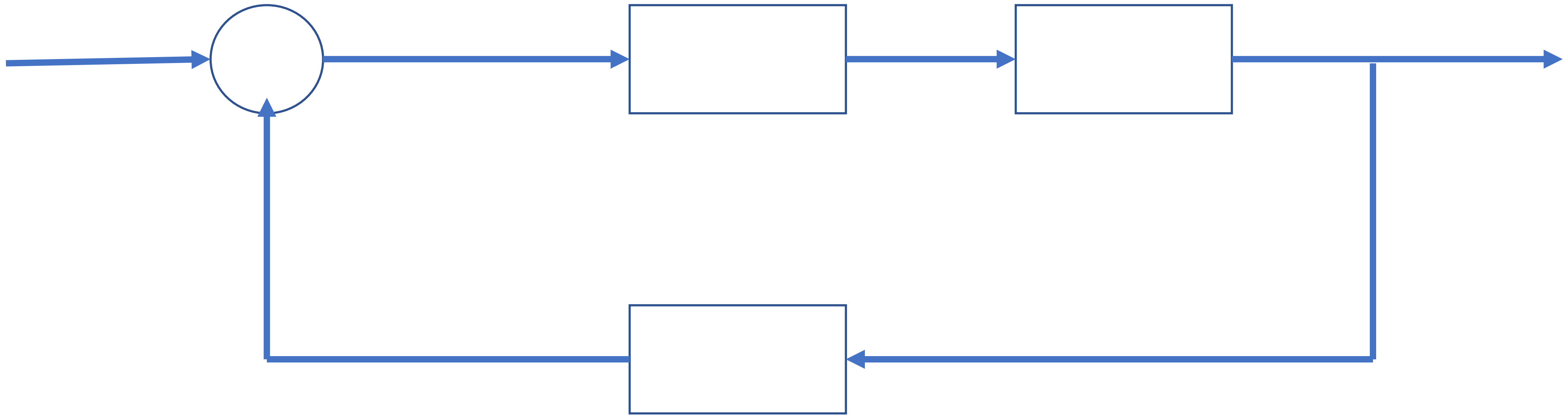
*1: SH725x includes EEPROM
*2: SH72567R includes FlexRay

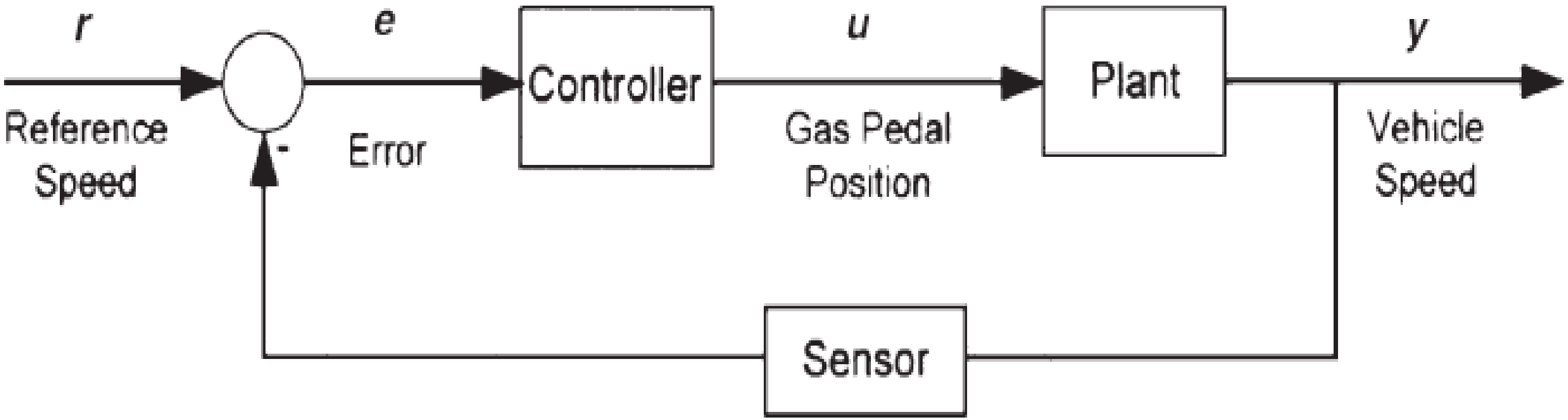
Class exercise

- Speed control in a car in rough terrain

  a) how does a human driver execute the control?

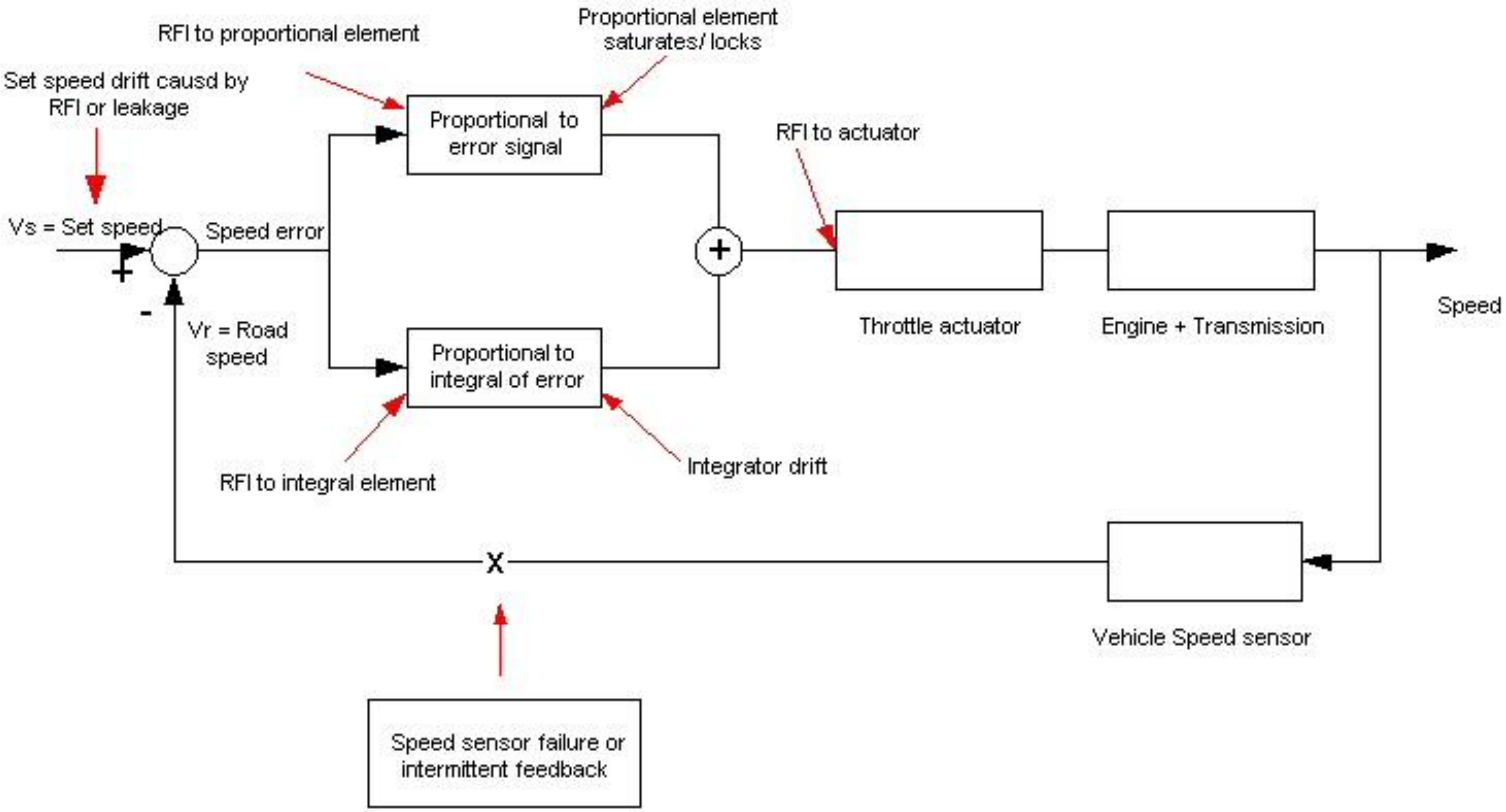
  b) Logical extension to an automatic control system – cruise control

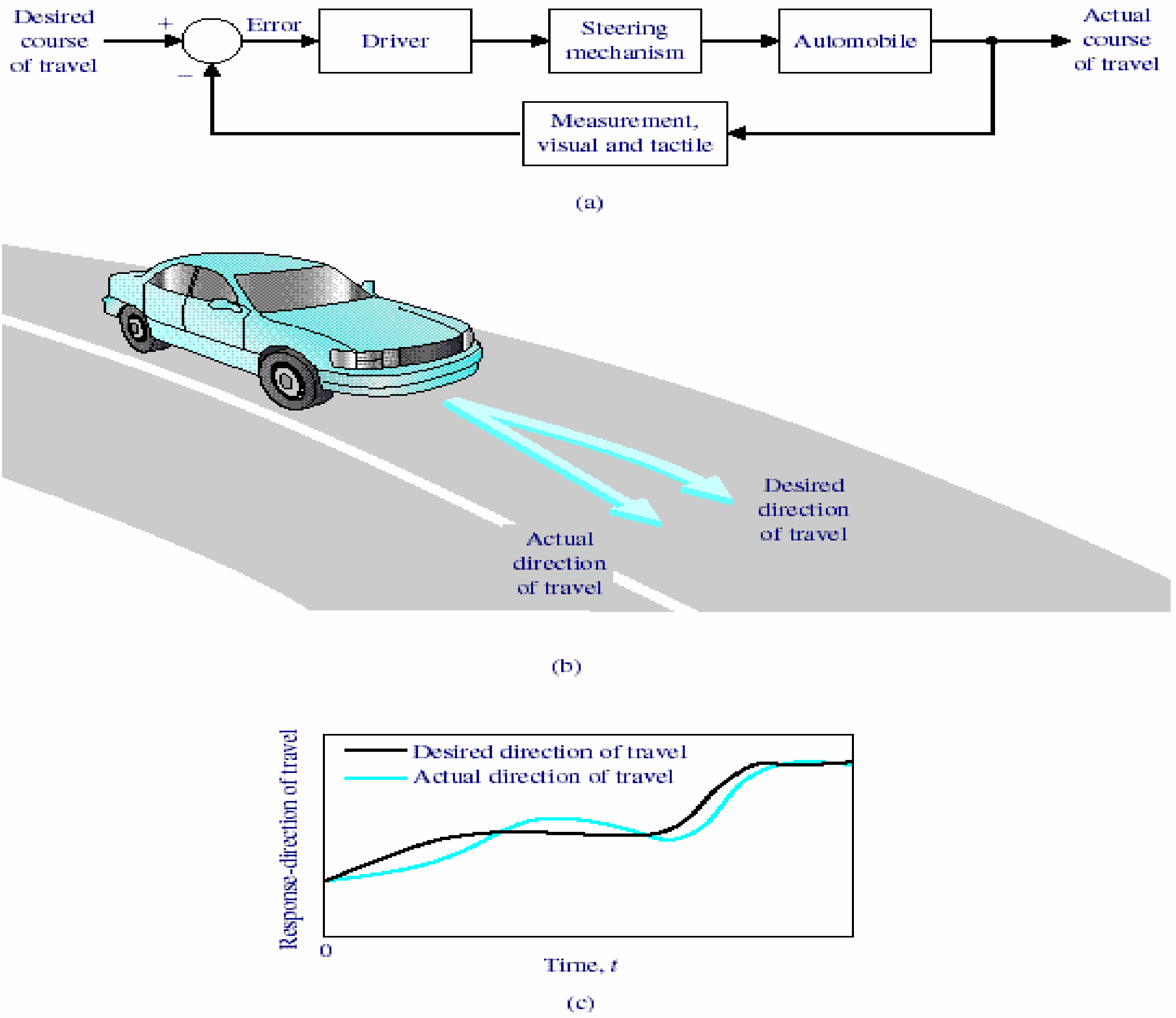




The car dynamics of interest are captured in the *plant*.
Information about the actual speed is fed back to the controller by *sensors*, and the control decisions are implemented via a device, the *actuator*, that changes the position of the gas pedal.
The knowledge of the car's response to fuel increases and decreases is most often captured in a mathematical model.

Cruise control





Steering control system

Control theory math

- Most require that the plants are linear, causal, and time invariant.

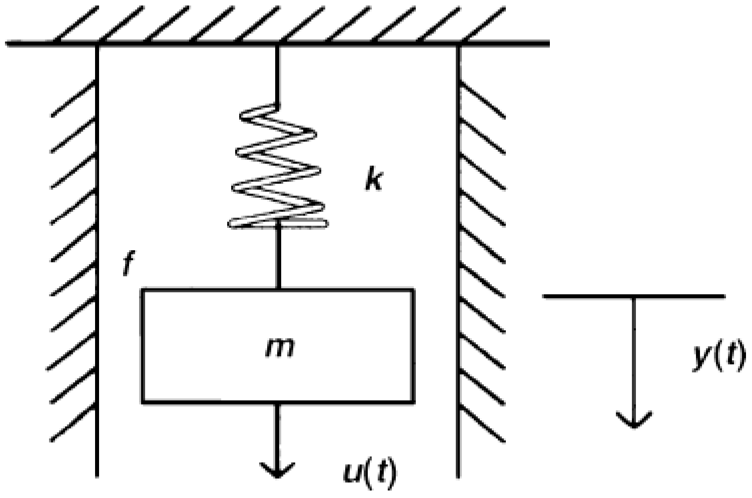
1)Linear ordinary differential equations

2) State variable or state space variable

3) Transfer function

are all that are required to model the plants.

Example: spring/mass/damper system



Motion is described by Newton's law, hence we

Start with:

$$\ddot{y}(t)+\frac{f}{m}\dot{y}(t)+\frac{k}{m}y(t)=\frac{1}{m}u(t)$$

Constraints:

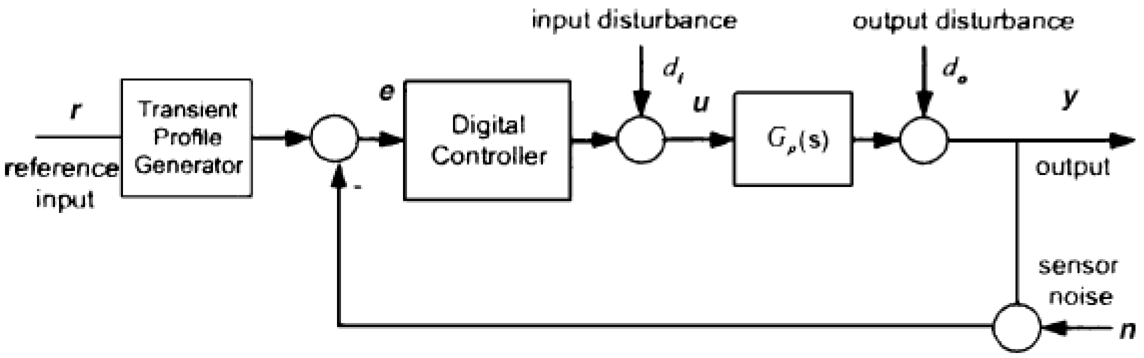
1. *Actuator Saturation*: The input *u* to the plant is physically limited to a certain range, beyond which it "saturates," i.e., becomes a constant.

2. *Disturbance Rejection and Sensor Noise Reduction*: There are always disturbances and sensor noises in the plant to be dealt with.

3.Dynamic Changes in the Plant: Physical systems are almost never truly linear nor time invariant.

4. *Transient Profile*: Transient profile is a mechanism to define the desired trajectory of *y* in transition, which is of great practical concerns. The smoothness of *y* and its derivatives, the energy consumed, the maximum value and the rate of change required of the control action are all influenced by the choice of transient profile.

5. *Digital Control*: Most controllers are implemented today in digital forms, which makes the sampling rate and quantization errors limiting factors in the controller performance



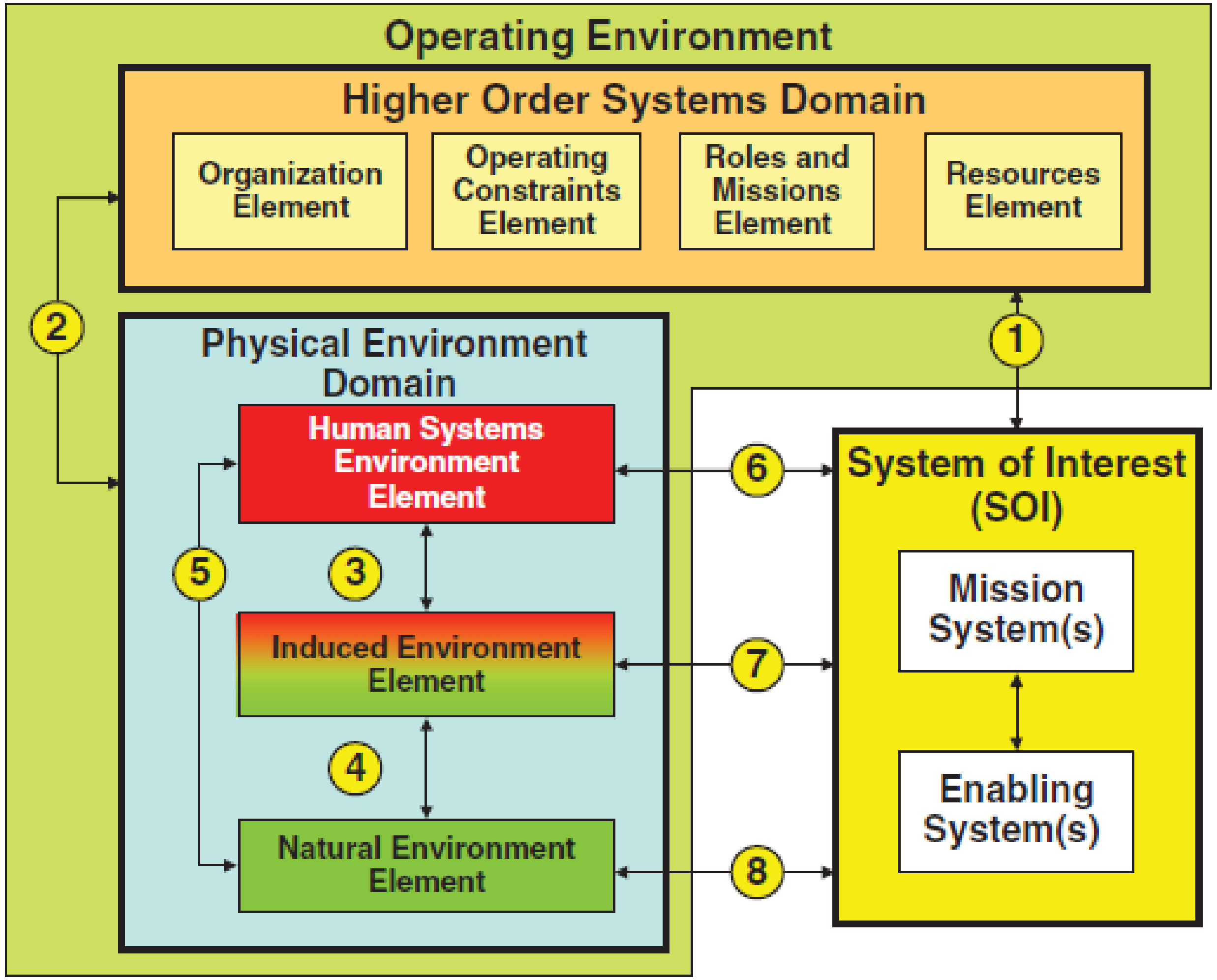
Control Design Strategy

- *Open-Loop Control*: If the plant transfer function is known and there is very little disturbance, a simple open loop controller, would satisfy most design requirements. Has been used as an economic means in controlling stepper motors, for example.
- *Feedback Control with a Constant Gain:* With significant disturbance and dynamic variations in the plant, feedback control of constant gain. Example: fixing the gain for an audio amplifier in a sound system.
- Proportional-integral-derivative (PID) controller

$$U \text{ (control signal)} = k_p + k_I \int e + k_D e^*$$

e is the current error
& e* is the trend

SOI’s Operating Environment (OE) Architecture



context diagram

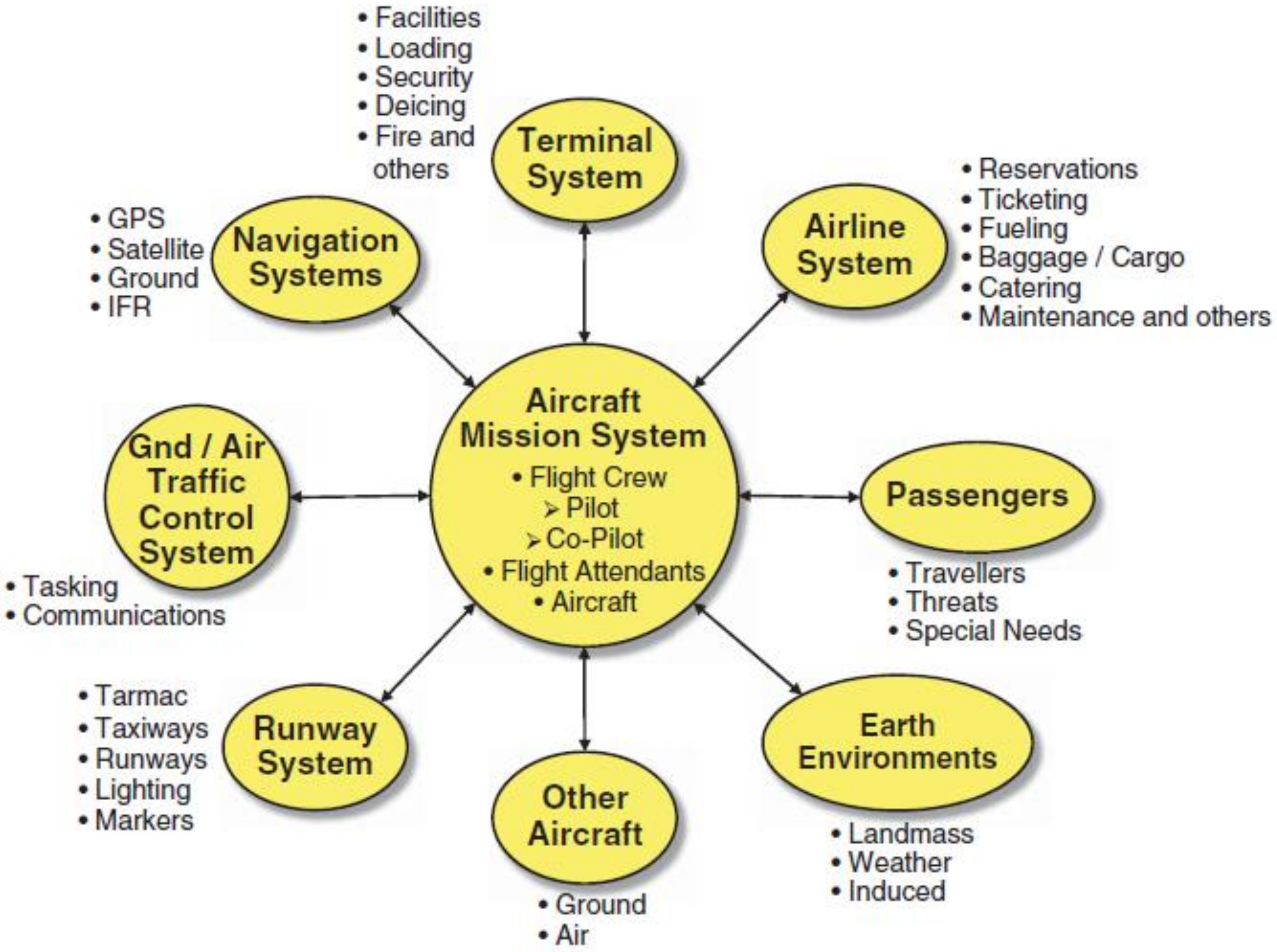
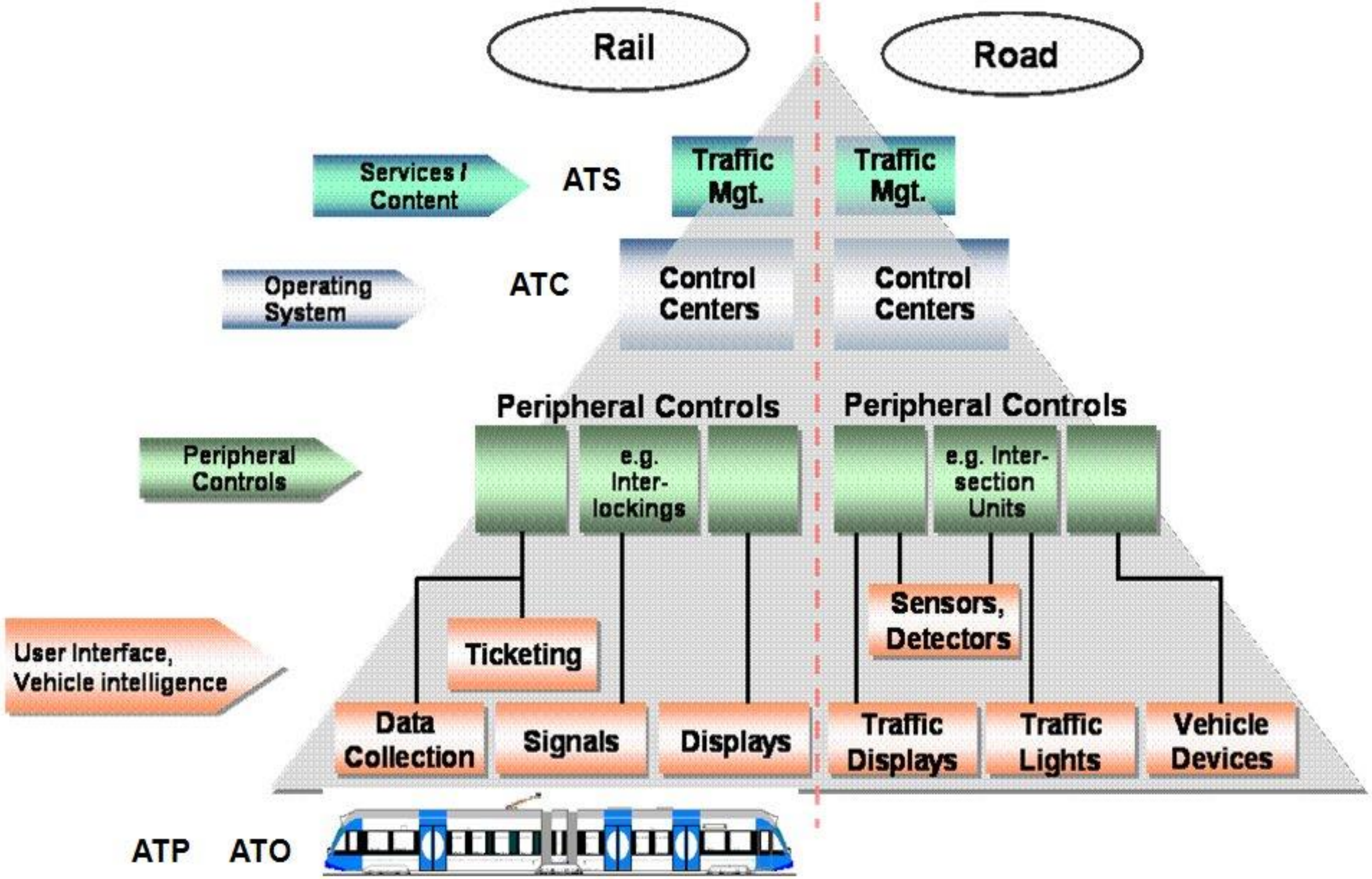


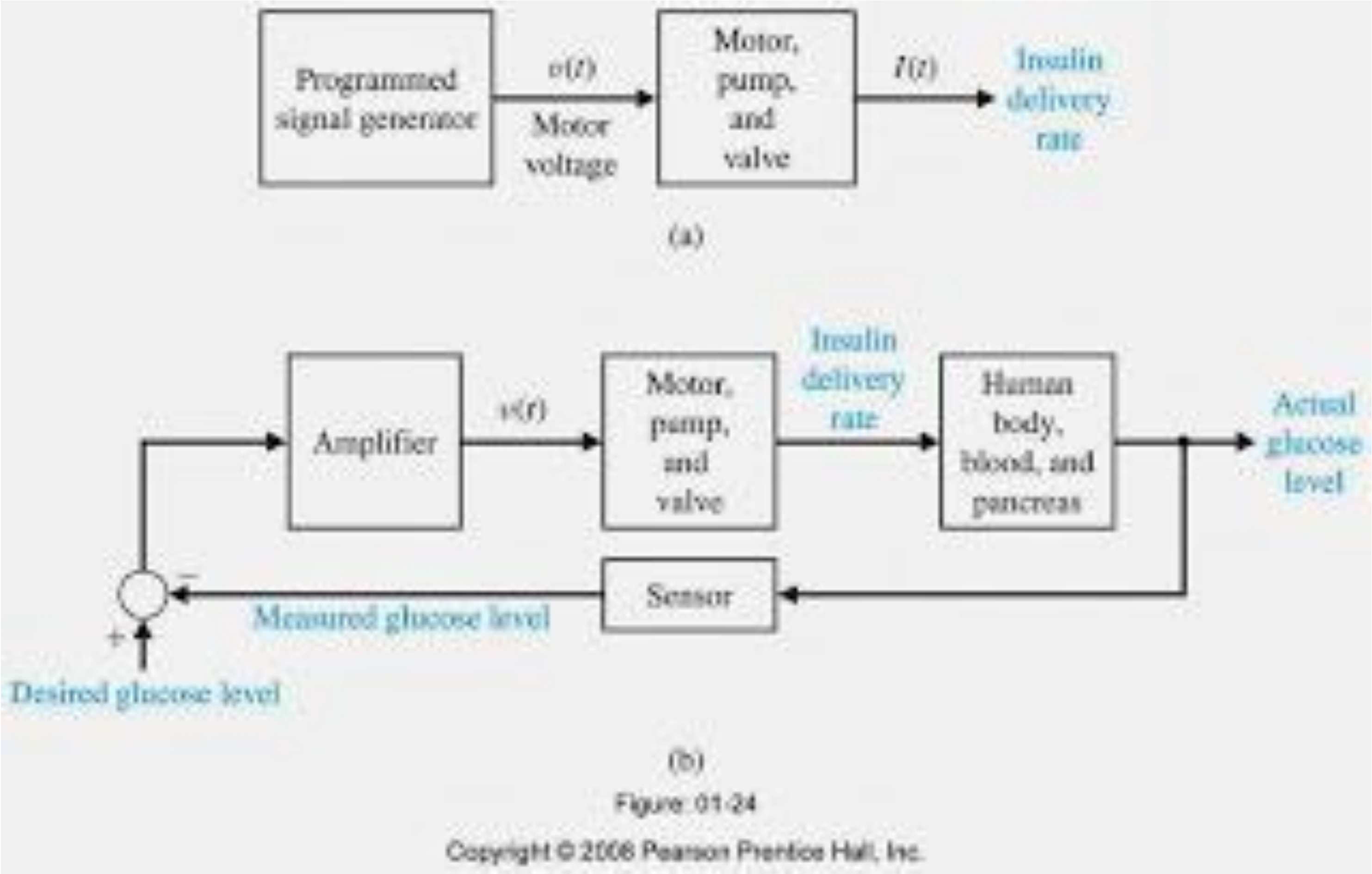
Figure 8.1 Context Diagram for an Aircraft Mission System

Source: Systems Engineering by Wasson

Railway signal control architecture



Example: The blood glucose and insulin levels for a healthy person.



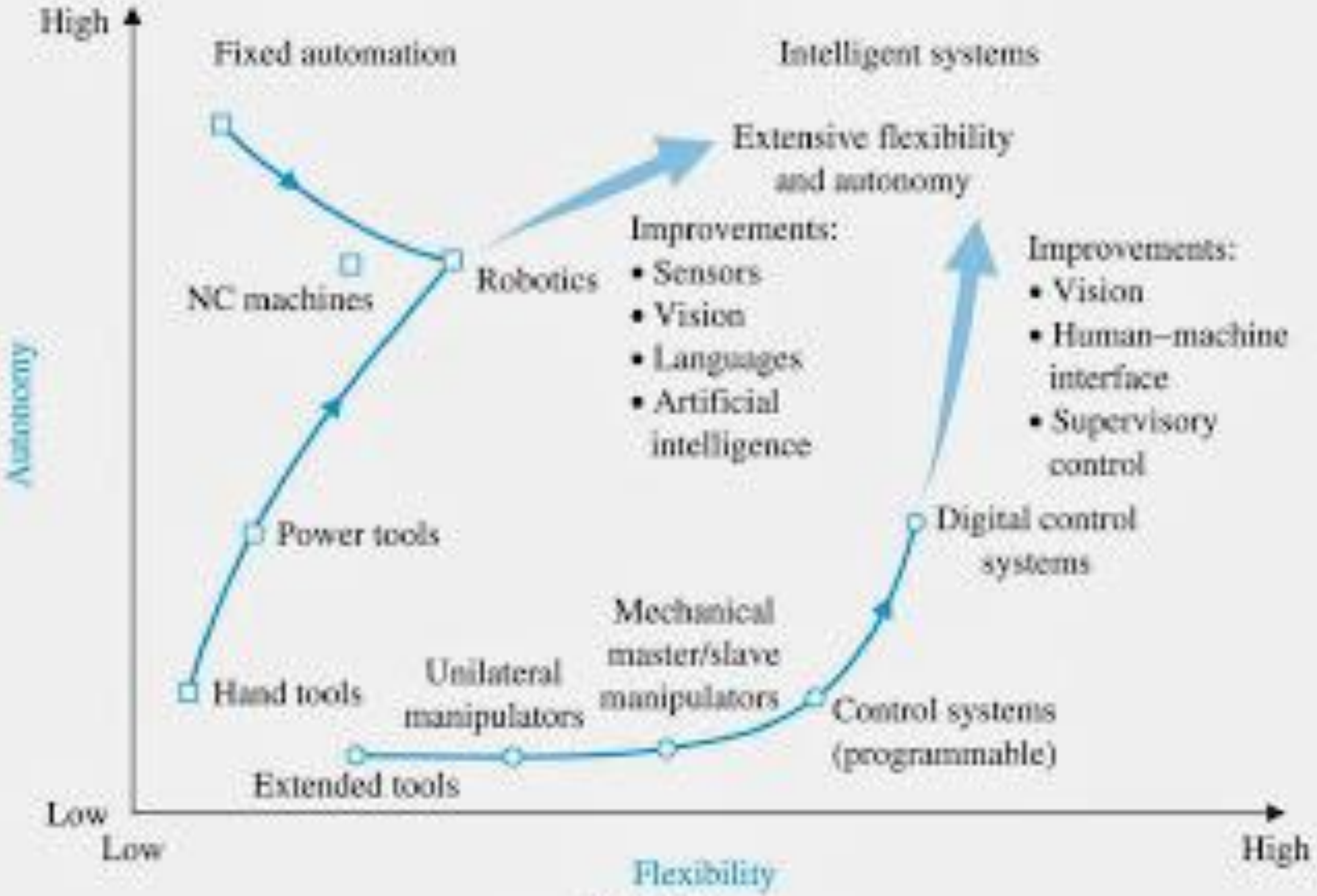
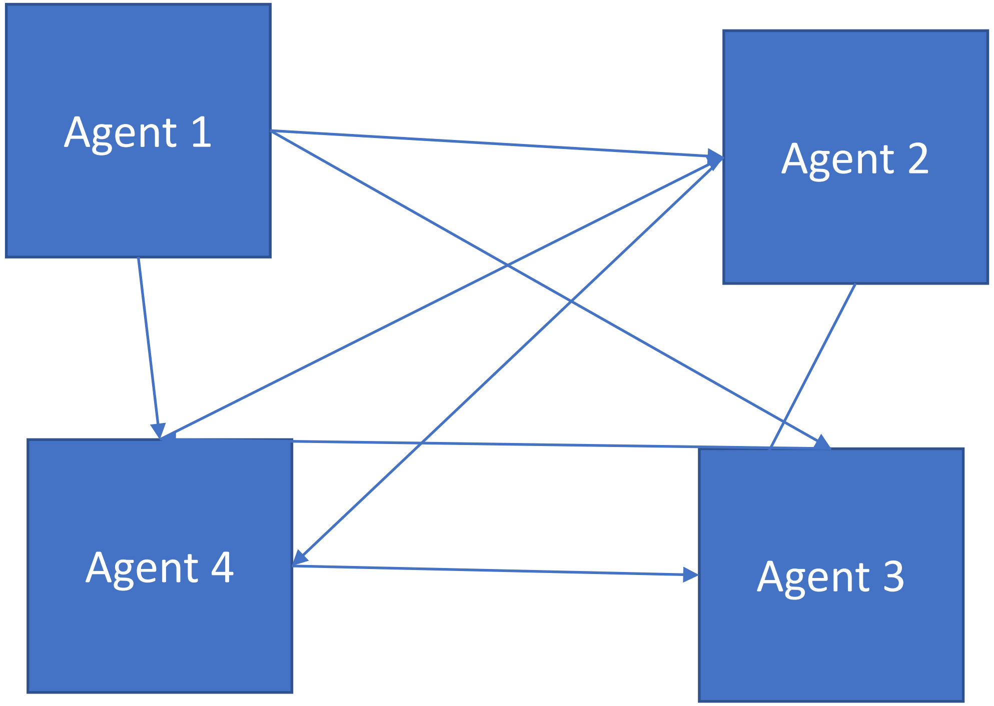
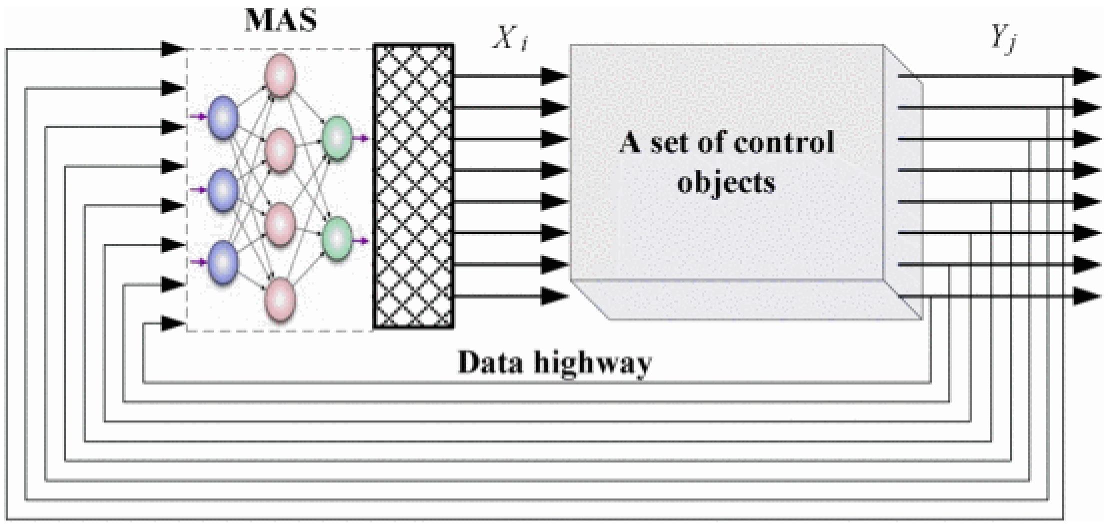

High
Fixed automation
Intelligent systems
Extensive flexibility
and autonomy
Improvements:
• Sensors
• Vision
• Languages
• Artificial
intelligence
Improvements:
• Vision
• Human–machine
interface
• Supervisory
control
NC machines
Robotics
Autonomy
Power tools
Digital control
systems
Mechanical
master/slave
manipulators
Unilateral
manipulators
Hand tools
Control systems
(programmable)
Extended tools
Low
Low
Flexibility
High

Figure 01-20

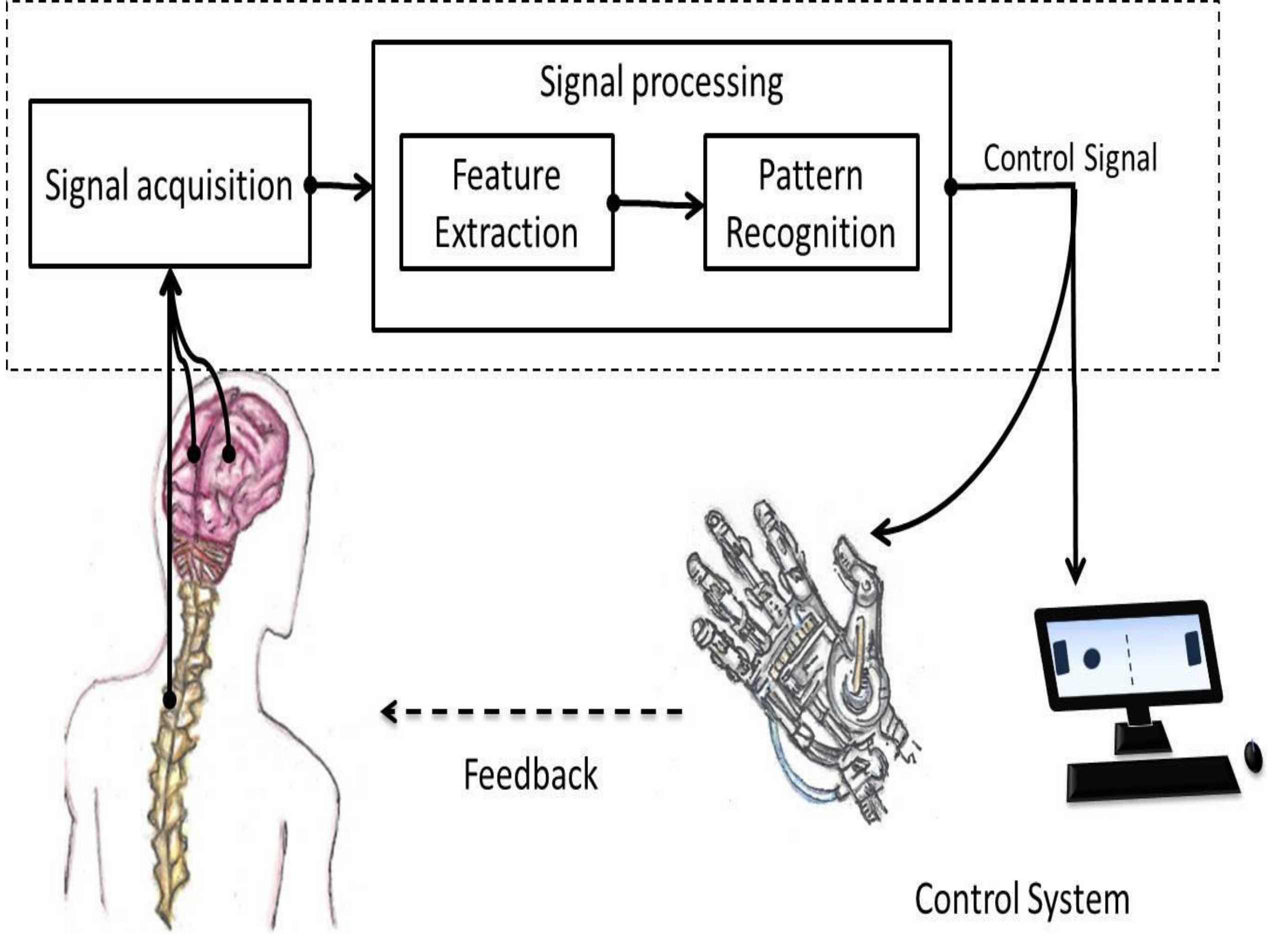
Complexity from Multi-agent systems



One Goal or desired response



Source: 2017 International Conference on Industrial Engineering, Applications and Manufacturing (ICIEA
A multi-agent control system of distributed generation plants



https://www.youtube.com/watch?v=DqeVNt5kK98