In the name of God

Modelling biological systems

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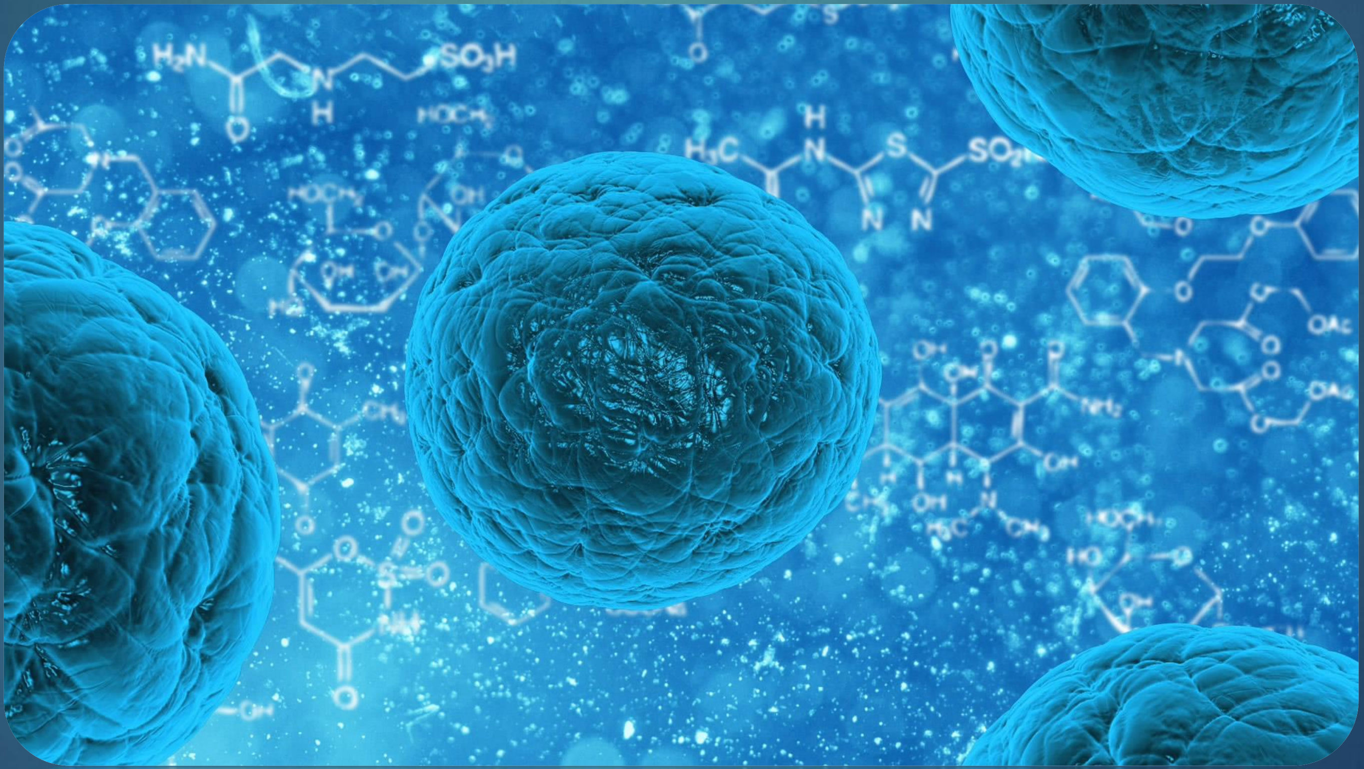


Analytical modeling

Stages of Analytical Modeling

- Determine Input-Output
- Determine primary and secondary variables
- Indicate the relationship between components of the system
- Find the dynamic (differential) equation
- Linearization of nonlinear equation
- Transform differential equation to algebraic (Laplace transformation)
- Obtain the relationship between input & output (transformation function)

Determine Input-Output

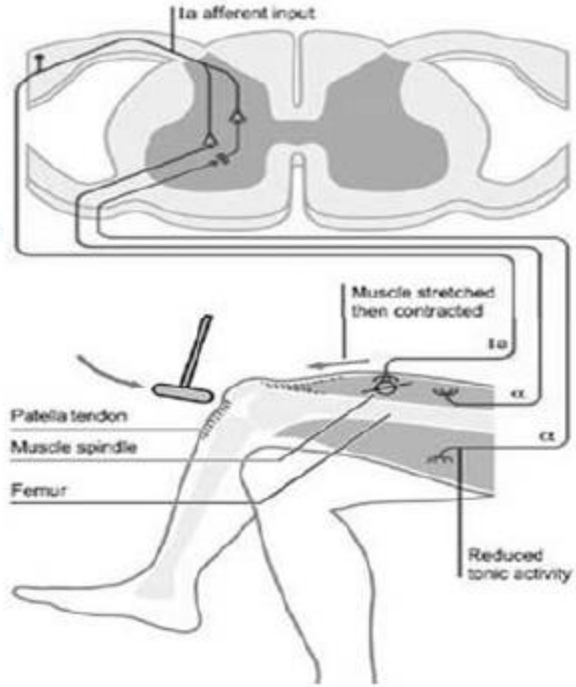
- The first stage in analytical modeling

EXAMPLE:

Modeling of muscle

Input : alpha or gamma fiber

Output : stiffness or length of muscle



Determine primary and secondary variables

- primary and secondary variables are studied as longitudinal and transverse variables in different systems
  - Longitudinal variables :
    - Don’t need source
    - Without alteration through passing the element
      - Electric current
      - Flow of fluid
  - Transverse variables :
    - Need a source to measure difference
      - Electric voltage
      - Hydraulic pressure

Determine primary and secondary variables

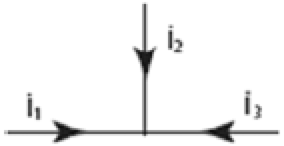
- With determined longitudinal and transverse variables we can obtain impedances (R,L,C) as secondary variables

- R: consume energy
- C: store electric energy
- L: store magnetic energy

Relationship between component of the system

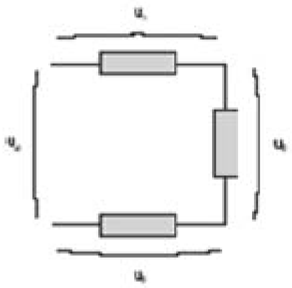
- **we should define the rules of Interactions between components**

  - **Example**
    - Kirchoff's laws
      - Currents sum to zero at interconnection points



$$\sum_k i_k = 0$$

      - Voltage drops around closed circuit equal zero

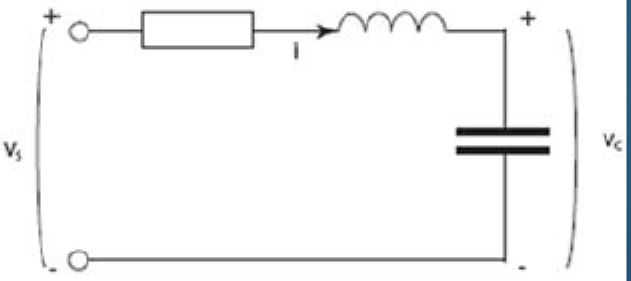


$$\sum_k u_k = 0$$

Find the dynamic (differential) equation

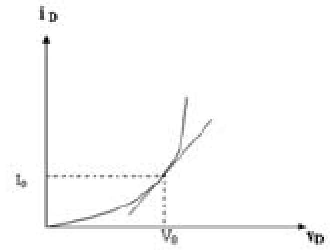
- We should organize the basic equation and find the relation between input & output
- For example we use “n” first order differential equation for system with order “n” to relate input to output
- Example:
  - RLC circuit

$$\begin{cases} v_s - Ri - L\dfrac{di}{dt} - v_c & = 0 \\ C\dfrac{dv_c}{dt} & = i \end{cases}$$



Linearization of nonlinear equation

- If system has nonlinear components try to linearize them in acceptable range
- Near a stationary point, the system is approximately linear
- for example linearization transistor around its stationary point (load point)



- For linearization around “$x=x_0$” we can use Taylor series expansion around $x=x_0$

$$y = f(x_o) + (x - x_o)\frac{df}{dx}\Big|_{x=x_o} + \frac{(x - x_o)^2}{2!}\frac{d^2 f}{dx^2}\Big|_{x=x_o} + \dots$$

Linearization of nonlinear equation

- If function depend on several variables then:

$$y = y_o + (x_1 - x_{10}) \left. \frac{df}{dx_1} \right|_{x_1 = x_{10}} + (x_2 - x_{20}) \left. \frac{df}{dx_2} \right|_{x_2 = x_{20}} + \ldots$$

- If the system are severely is nonlinear or the range of variation is extended then piece-wise linearization will be used and according to the range of input one relationship is considered.

Modeling of Analog Systems

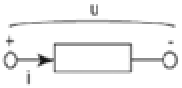
- Electrical
- Mechanical
- Hydraulic
- Chemical
- Thermal
- Magnetic
- Social
- Economic
- Traffic
- Psychology

Each of the above models can be divided into several states

Electrical Systems

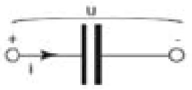
- **Primary variables**
  - **Longitudinal variables : current**
  - **Transverse variables : voltage**

- **Secondary variables**
  - **Resistive elements :** $u(t) = Ri(t)$



  - **Inductors :** $i(t) = \frac{1}{L}\int_0^t u(s)\,ds \qquad L\frac{di(t)}{dt} = u(t)$

  - **Capacitors :** $u(t) = \frac{1}{C}\int_0^t i(s)\,ds \qquad C\frac{du(t)}{dt} = i(t)$



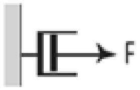
Mechanical Systems

- Translational
- Rotational
- Hydraulic
- Thermal

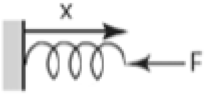
Translational

- Primary variables
  - Longitudinal variables : force
  - Transverse variables : velocity

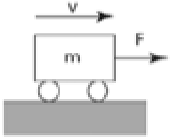
- Secondary variables
  - Damper : $F(t) = \gamma v(t)$



  - Spring : $F(t) = k\int_0^t v(s)\,ds \qquad \frac{1}{k}\frac{d}{dt}F(t) = v(t)$



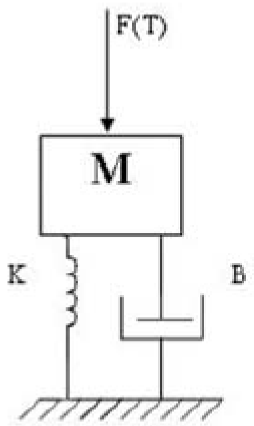
  - Mass : $v(t) = \frac{1}{m}\int_0^t F(s)\,ds \qquad m\frac{d}{dt}v(t) = F(t)$



Translational

- **Example :**

Write the mathematical model and plot the electrical model



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Grazie
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