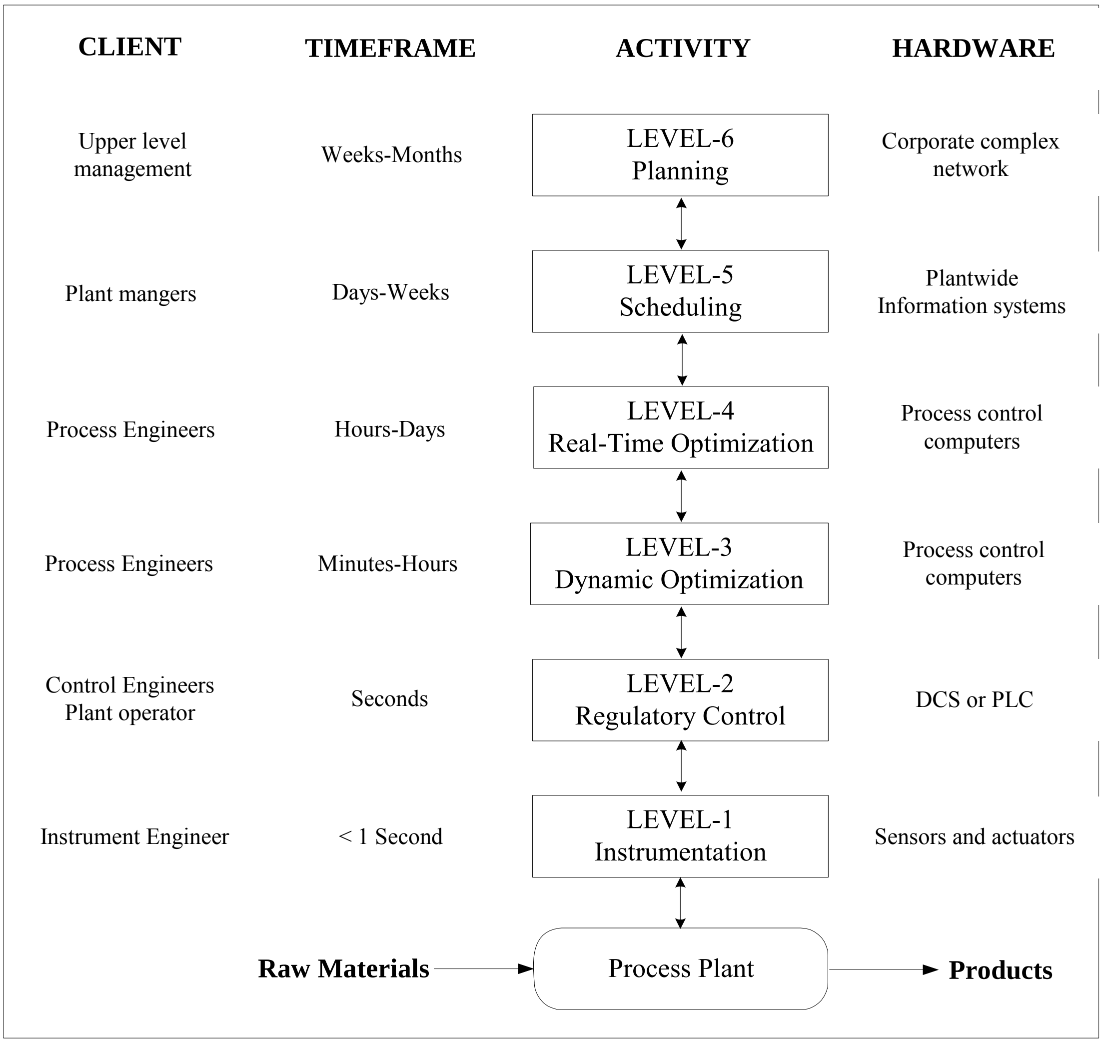
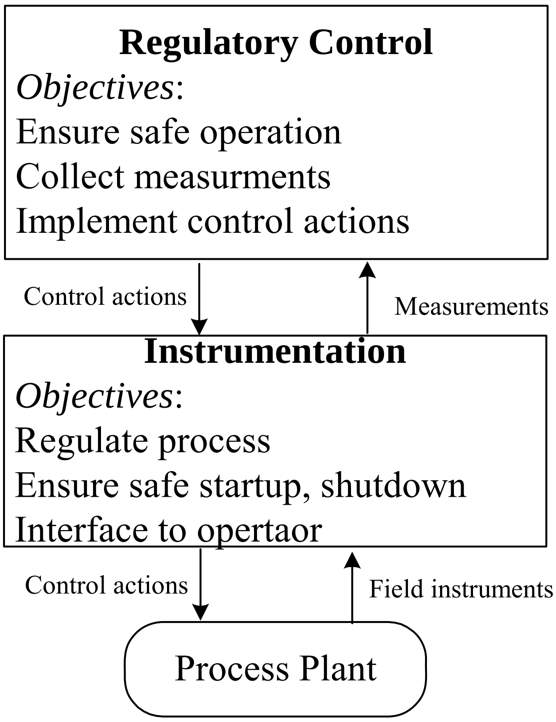
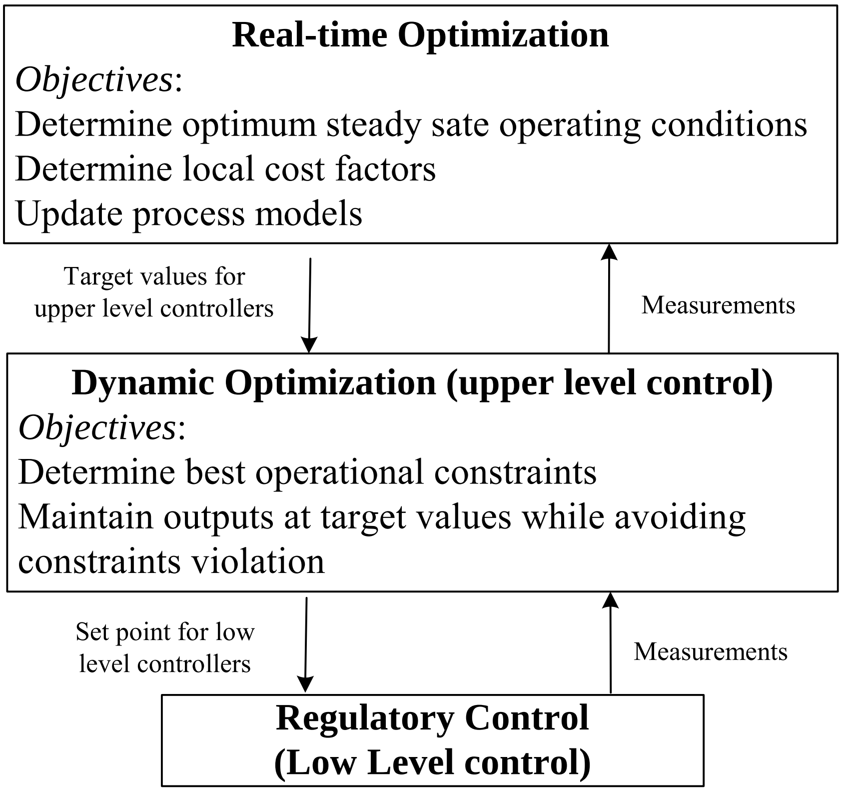
CHAPTER 1:

PEREVIEW

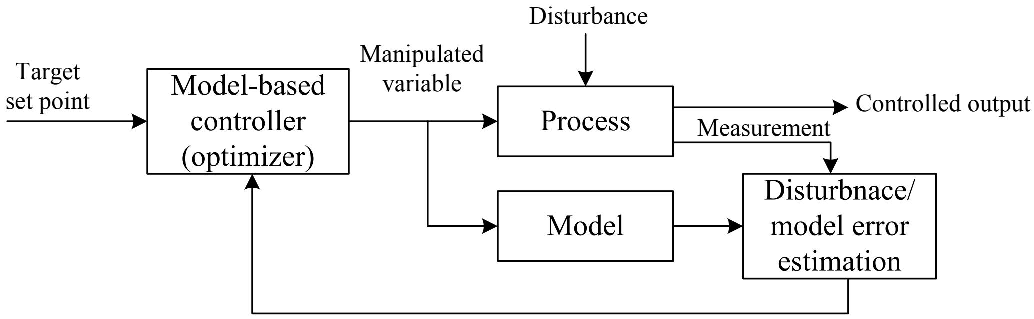
1. Nature of Process Control Problem




Regulatory Control
Objectives:
Ensure safe operation
Collect measurments
Implement control actions
Control actions
Measurements
Instrumentation
Objectives:
Regulate process
Ensure safe startup, shutdown
Interface to opertaor
Control actions
Field instruments
Process Plant


Real-time Optimization
Objectives:
Determine optimum steady sate operating conditions
Determine local cost factors
Update process models
Target values for
upper level controllers
Measurements
Dynamic Optimization (upper level control)
Objectives:
Determine best operational constraints
Maintain outputs at target values while avoiding
constraints violation
Set point for low
level controllers
Measurements
Regulatory Control
(Low Level control)

2. Model-Based Controller (optimizer)



The major blocks associated with Model-based controller:

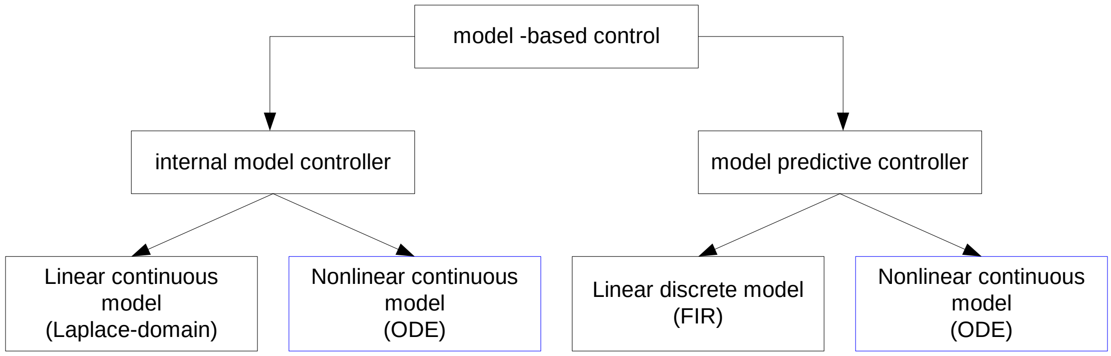
1. The process model
2. Disturbance /model error estimation
3. Controller or optimizer

The major drawback of model-based controller is the accuracy of the model.

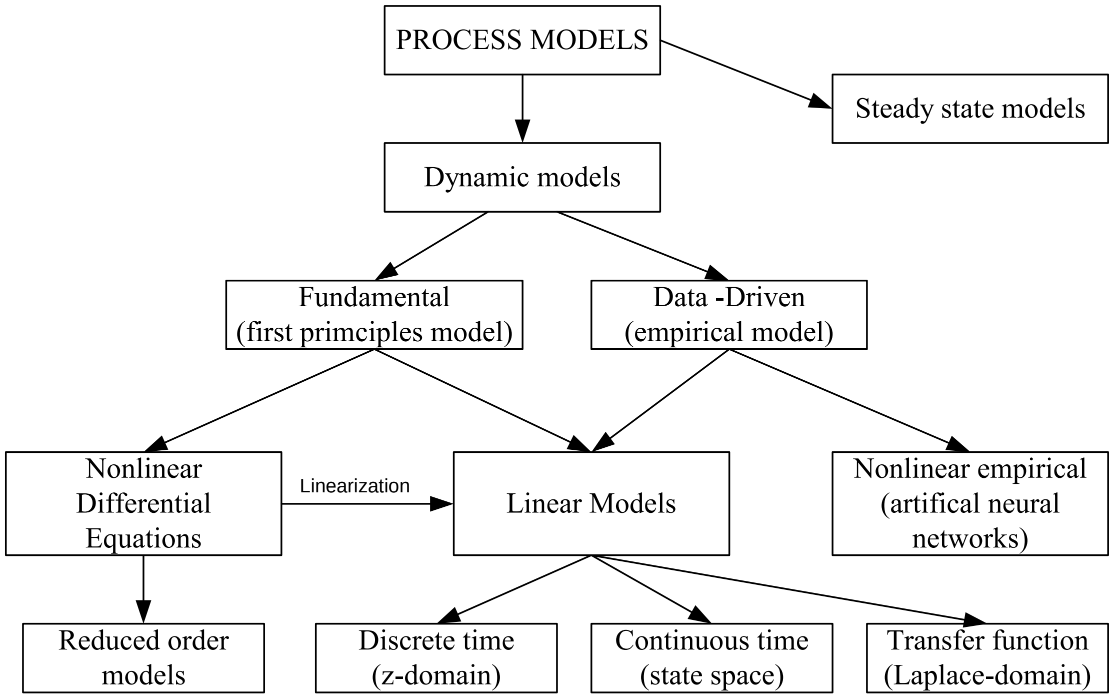
The process model is used at almost all layers of the hierarchal structure:

- Regulatory control: Models are used to tune PID controller, feed-forward, inferential controller
- Dynamic optimization: Models are used to predict the behavior of the process in the future, compute control actions.
- Real-time (steady state) optimization: Models are used to compute steady state operating conditions.
- Linear models are also used for planning and scheduling.

3. Types of Model-Based Controller



4. Types of Models



4.1. Time Domain models (state Space)

Nonlinear state space:

$$\frac{dx}{dt} = f(x, u, w)$$
$$y = g(x, u)$$

Linear state space:

$$\frac{dx}{dt} = Ax(t) + Bu(t) + Dw(t)$$
$$y = Cx(t)$$

4.2 Laplace Domain models

$$sx(s) = Ax(s) + Bu(s) + Dw(s)$$
$$y(s) = Cx(s)$$

$$y(s) = C(sI - A)^{-1} Bu(s) + C(sI - A)^{-1} Dw(s) \equiv G_p(s)u(s) + G_w(s)w(s)$$

$$G(s) = \frac{a_n s^n + a_{n-1} s^{n-1} + \cdots + a_1 s + a_0}{b_m s^m + b_{m-1} s^{m-1} + \cdots + b_1 s + b_0}$$

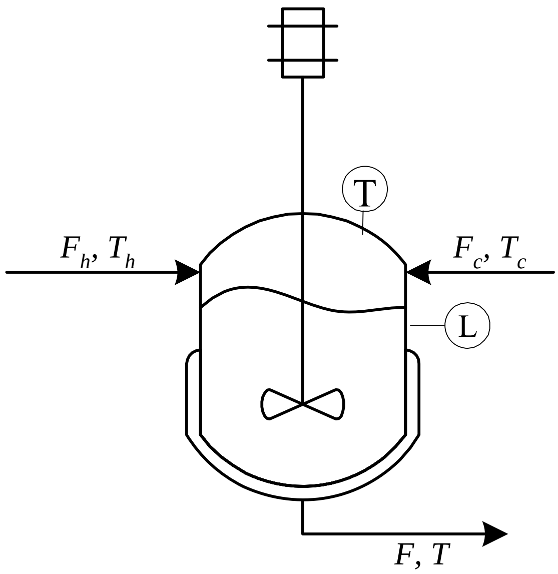
4.3 Building State Space model from first principles

Example: Mixing Tank

Mass Balance:

$$A\rho \frac{dh}{dt} = F_c\rho_c + F_h\rho_h - F\rho$$

$$A\frac{dh}{dt} = F_c + F_h - F$$



Energy Balance:

$$\frac{d}{dt}\rho AhCpT = \rho F_c CpT_c + \rho F_h CpT_h - \rho FCpT$$

$$A\frac{d}{dt}hT = F_c T_c + F_h T_h - FT$$

$$Ah\frac{dT}{dt} + AT\frac{dh}{dt} = F_c T_c + F_h T_h - FT$$

$$Ah\frac{dT}{dt} = F_c(T_c - T) + F_h(T_h - T)$$

The state space equations:

$$A\frac{dh}{dt} = F_c + F_h - F \equiv f_1(F_c, F_h, F)$$

$$Ah\frac{dT}{dt} = F_c(T_c - T) + F_h(T_h - T) \equiv f_2(F_c, F_h, T_c, T_h, T)$$

Define:

$$\mathbf{x} = \begin{bmatrix} h \\ T \end{bmatrix}; \qquad \mathbf{u} = \begin{bmatrix} F_c \\ F_h \end{bmatrix}; \qquad \mathbf{f} = \begin{bmatrix} f_1 \\ f_2 \end{bmatrix}$$

Linearize:

$$\mathbf{A} = \frac{\partial \mathbf{f}}{\partial \mathbf{x}} = \begin{bmatrix} 0 & 0 \\ 0 & -(F_c + F_h) \end{bmatrix}_{ss}$$

$$\mathbf{B} = \frac{\partial \mathbf{f}}{\partial \mathbf{u}} = \begin{bmatrix} 1 & 1 \\ T_c - T & T_h - T \end{bmatrix}_{ss}$$

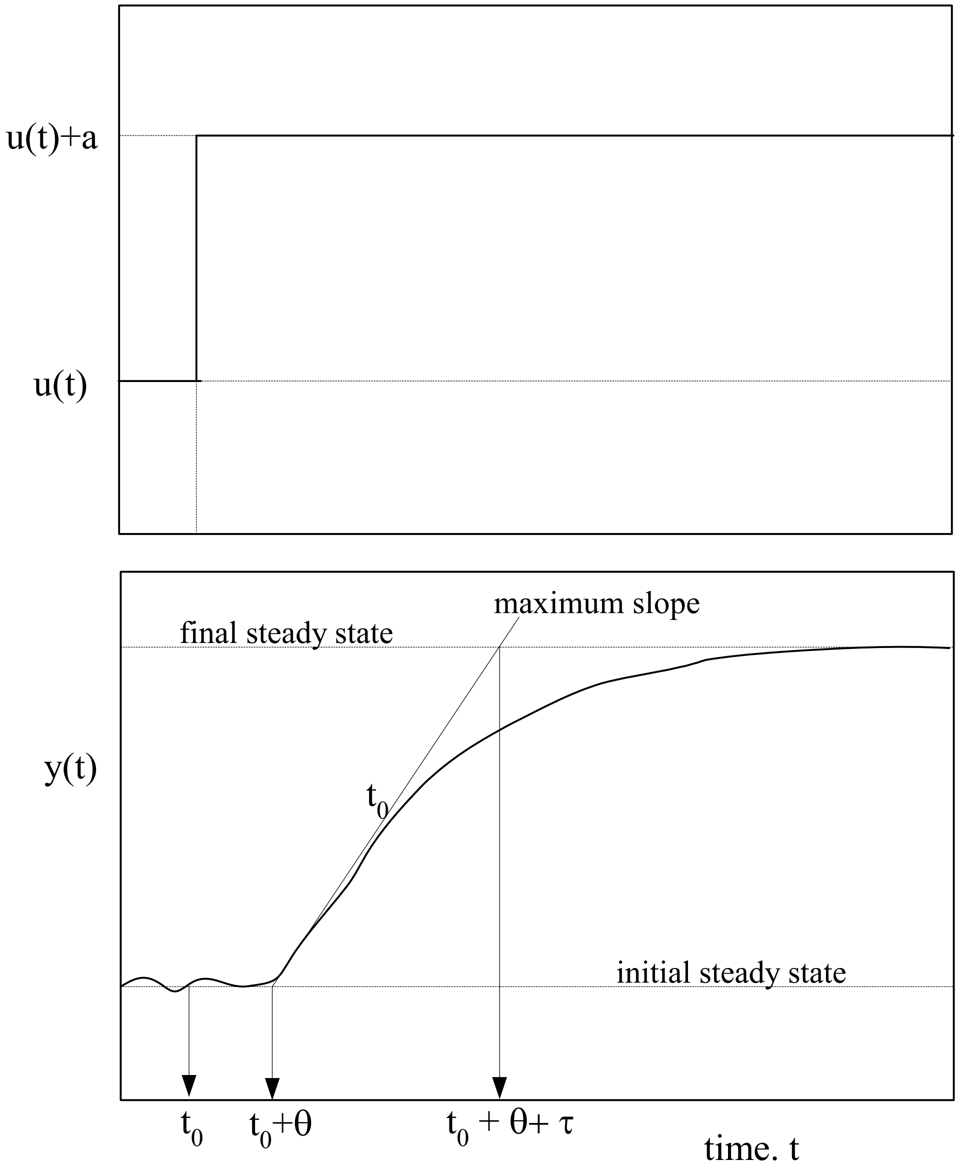
$$D = \frac{\partial \mathbf{f}}{\partial w} = \begin{bmatrix} 0 & 0 \\ 0 & 0 \end{bmatrix}_{ss}$$

$$C = [1 \quad 1]$$

$$\frac{d\mathbf{x}}{dt} = \mathbf{Ax}(t) + \mathbf{Bu}(t)$$
$$\mathbf{y} = \mathbf{Cx}(t)$$

3.4 Identifying a first-order process with dead time

$$G(s) = \frac{ke^{-\theta s}}{\tau s + 1}$$



5. Properties of Transfer Function

$$G(s) = \frac{N(s)}{D(s)} = \frac{b_m}{a_n} \frac{(s - z_1)(s - z_2)\cdots(s - z_m)}{(s - p_1)(s - p_2)\cdots(s - p_n)}$$

Pole: is the root of the denominator of the transfer function, i.e. the root of the characteristic polynomial. It directly determines:

- The stability of the system (positive poles)
- The potential of periodic transient (imaginary poles)

Zero: is the root of the numerator of the transfer function. It determines an inverse response (positive zero).

Casuality: A physical system is *causal* when the order of the denominator is greater than the numerator, and when the transfer function goes to 0 as $s \rightarrow \infty$, the system is hence *strictly proper*. If the transfer function contains $e^{\theta s}$ or the order of numerator is higher than the denominator, then the system is *non-casual* or *not realizable* because the current values of the system depends on the future values of the variables.

Steady state gain: is the steady state value of the transfer function, is evaluated by setting $s = 0$ in the stable transfer function.

5.1 Effect of poles and zeros

The poles and zeros of a transfer function affect the dynamic of a process.

Consider a particular transfer function:

$$G(s) = \frac{K}{s(\tau_1 s + 1)(\tau^2 s^2 + 2\zeta\tau s + 1)}$$

The poles, i.e. the roots of the characteristic equation are:

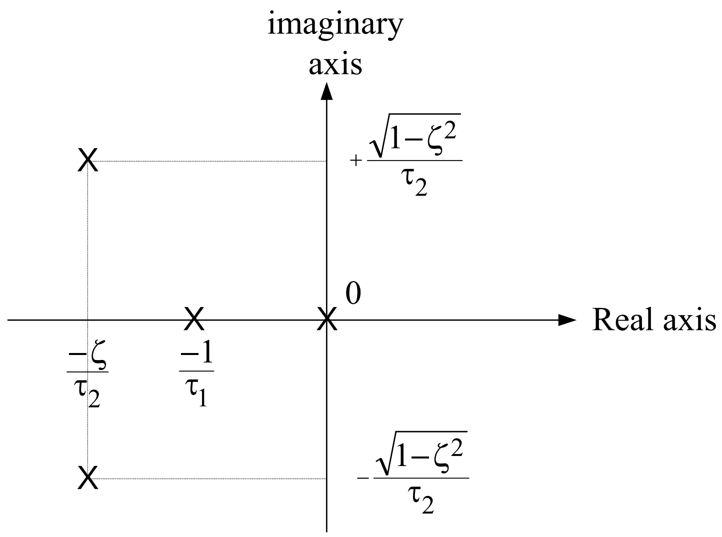
$$s_1 = 0$$

$$s_2 = -\frac{1}{\tau_1}$$

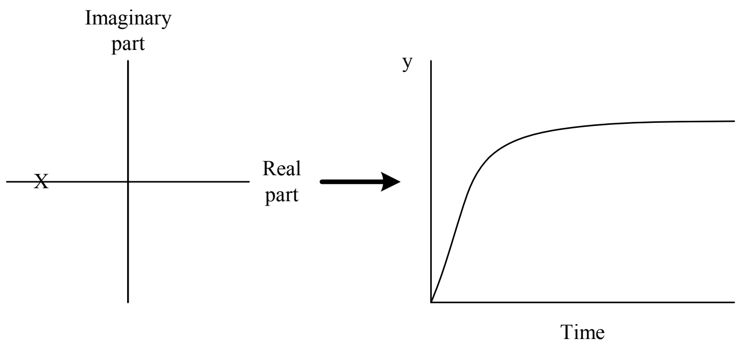
$$s_3 = -\frac{\zeta}{\tau_2} + j\frac{\sqrt{1-\zeta^2}}{\tau_2}$$

$$s_4 = -\frac{\zeta}{\tau_2} - j\frac{\sqrt{1-\zeta^2}}{\tau_2}$$

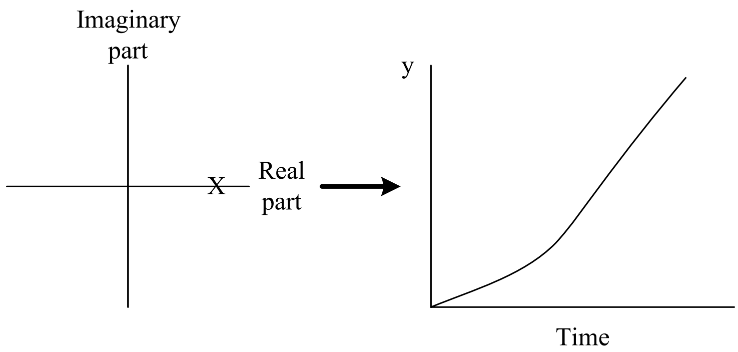
The poles can be represented in the complex plane as follows:



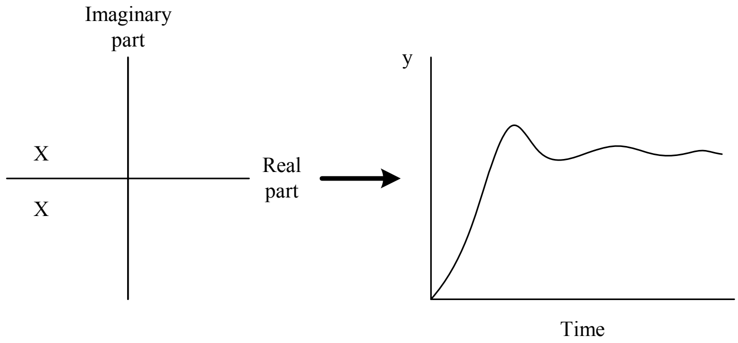
- Complex poles indicate the response will contain sine and cosine modes, i.e. will exhibit oscillation.
- Negative poles will result in a stable decaying response.
- Positive poles indicate that the response will have unstable mode.



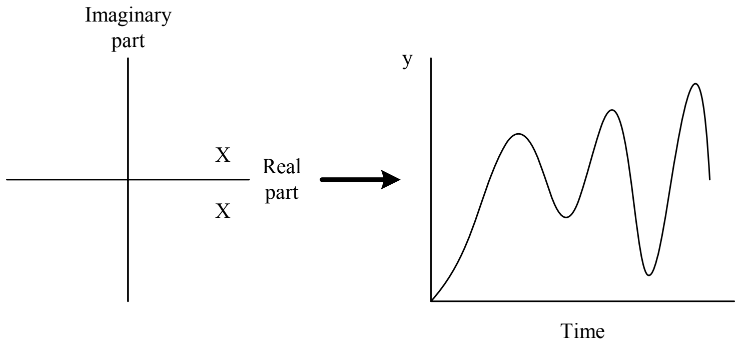
Negative real root



Positive real root



Complex roots with negative real part



Complex roots with positive real part

- A process with RHP zeros is called non-minimum-phase
- A process with odd number of RHP zeros has an inverse response.