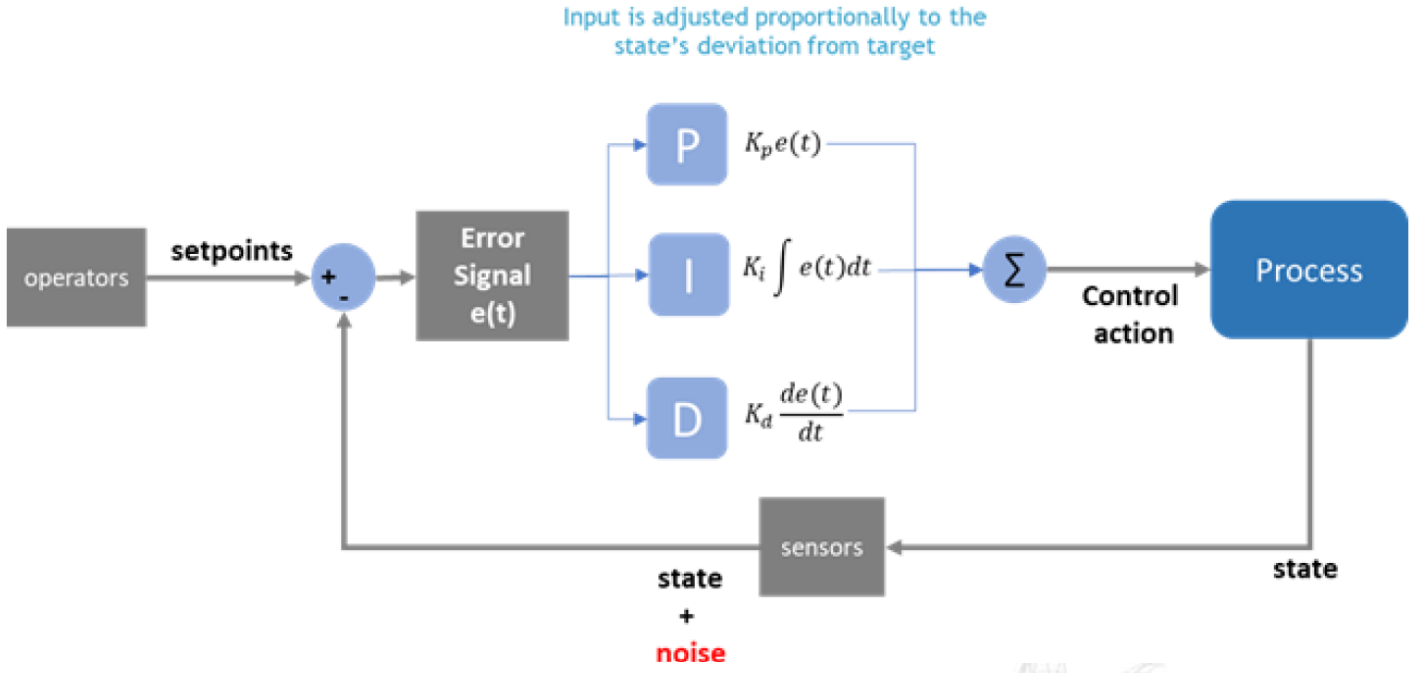
Modern Control Theory

Model Predict Control - MPC – Lecture 1

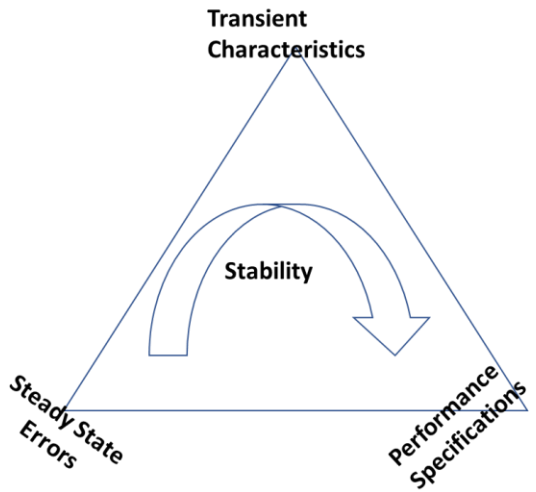
Introduction

PID controls – fundamental block

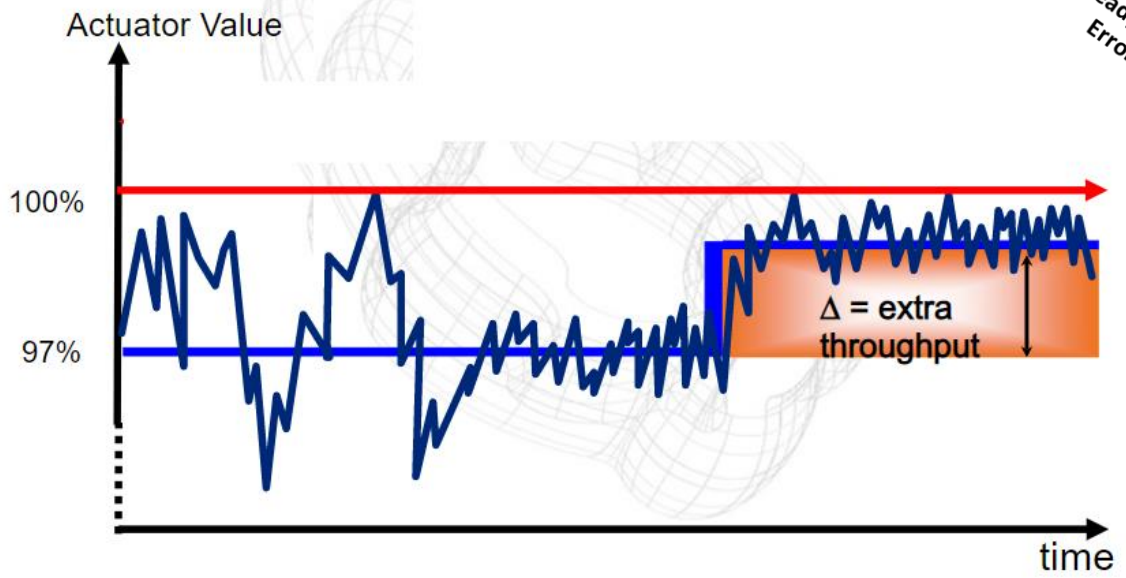


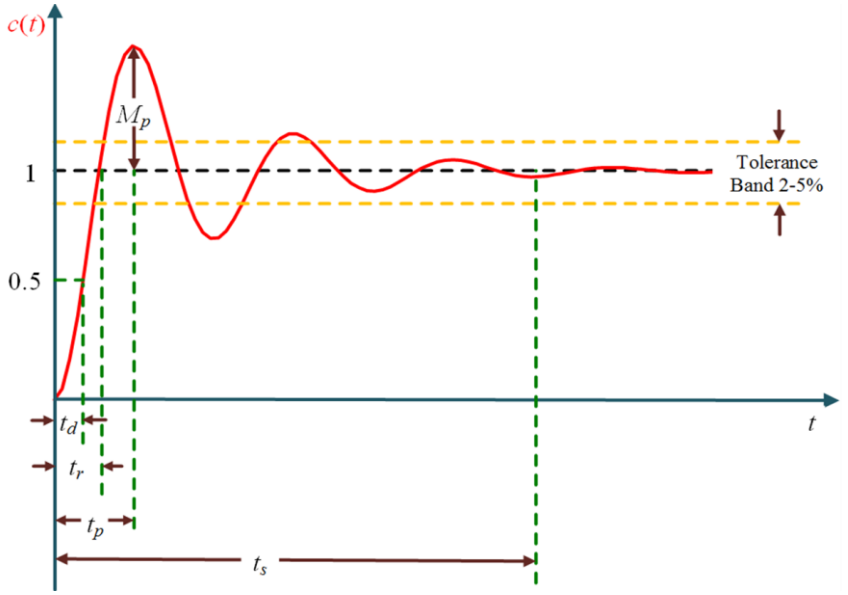
How many control loops are there in a refinery

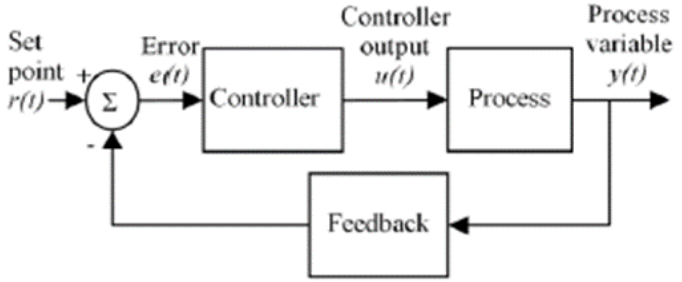
a. 10-100
b. 1-10
c. 1000-2000
d. 100-500



- Design –
- mainly offline,
- Gets complex with multi loops
- doesn't cater to changing conditions
- Focus on local performance with limited incorporation of disturbance effects

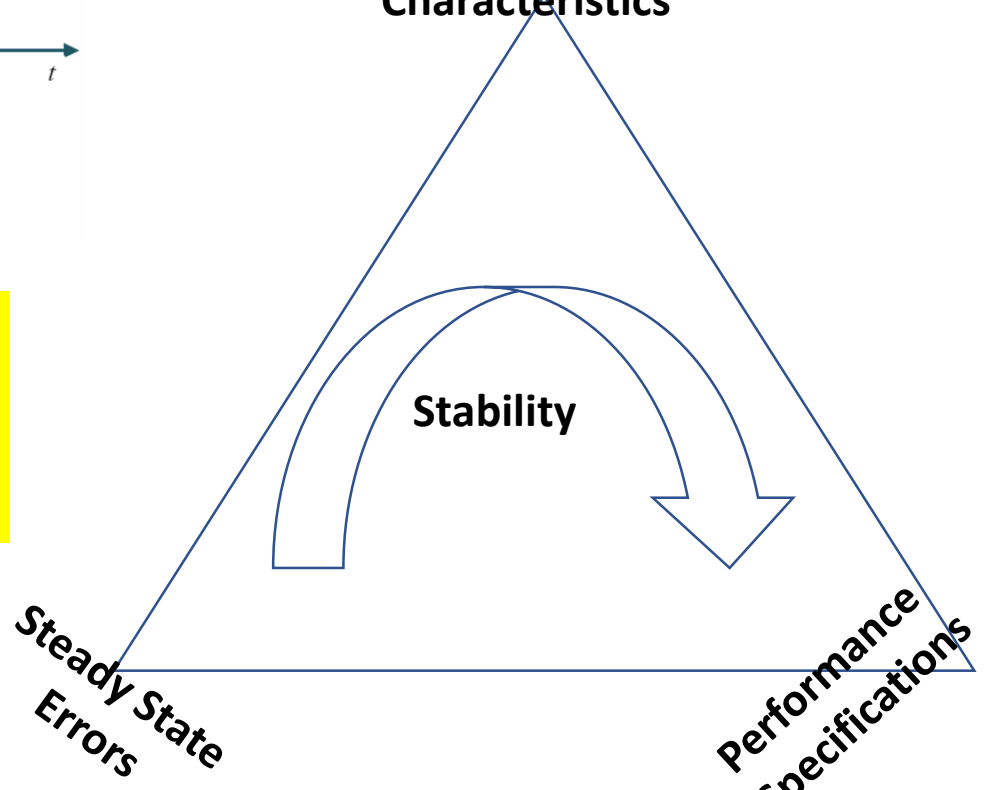


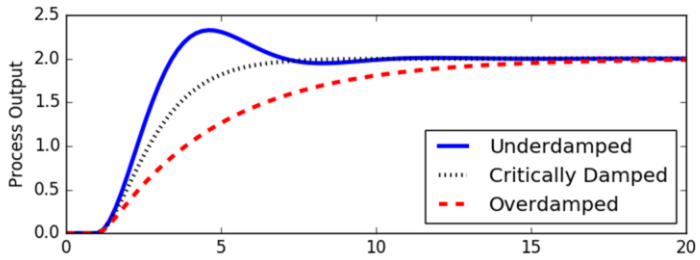




Transient Characteristics

Handling Transients & Steady State Errors, while ensuring Stability and Adherence to Performance Specifications





$$\lim_{t\to 0^+} f(t) = \lim_{s\to\infty} sF(s) = f(0^+)$$

What is MPC (1/5)?

Scenario 1

Speed of car = 60km/hr

Distance = 2 km

Speed?

Signal Red light for 30 secs

What will be the action?

Slow down the car?

Go at the same speed?

Reduce slightly and increase after signal?

Speed profile

Why this action?

Scenario 2

Speed of car = 60km/hr

Distance = 0.75 km

Speed?

Signal Red light for 30 secs

What will be the action?

Slow down the car?

Go at the same speed?

Reduce acceleration and increase after signal?

Why this action?

Scenario 3

Speed of car = 60km/hr

Distance = 0.5 km

Speed?

Signal Red light for 30 secs

What will be the action?

Slow down the car?

Go at the same speed?

Reduce acceleration and increase after signal?

Why this action?

What is MPC (2/5)

- What objectives the actions were serving?
  - Break as less as possible
  - Slow down as minimal from ?
- Why?
  - Fuel efficiency/ cost saving
- Constraints?
  - Signal violation?
  - Abrupt braking?

- CV – controlled variable - SPEED
- MV – Manipulated variable – Fuel injection, Break
- DV – Disturbance variable - time duration in red light, time interval for red light

First definition of MPC:

MPC is a controller which uses prediction to decide the current/future control actions such that to satisfy the desired objectives without violation of constraints.

Was there a model here?

What is MPC (3/5)

- Second example - Beating the opponent in 3 moves

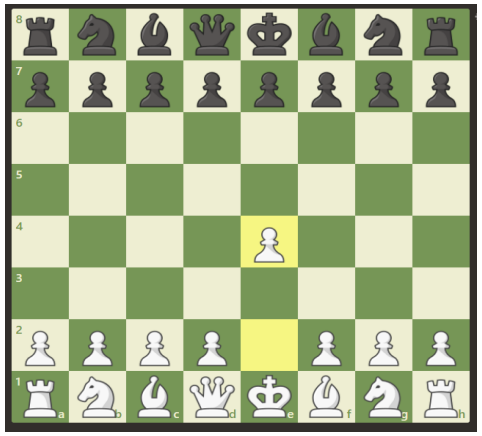
Winner

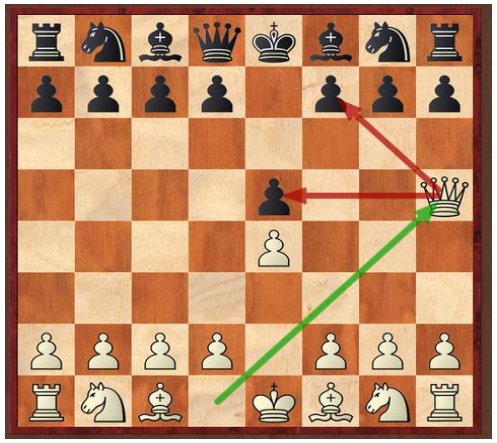
Loser

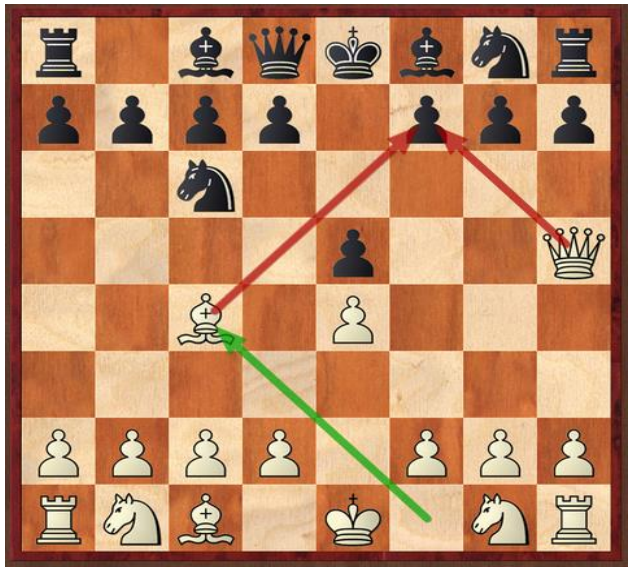
What is MPC (4/5)

- Second example - Beating the opponent in 4 moves

Winner







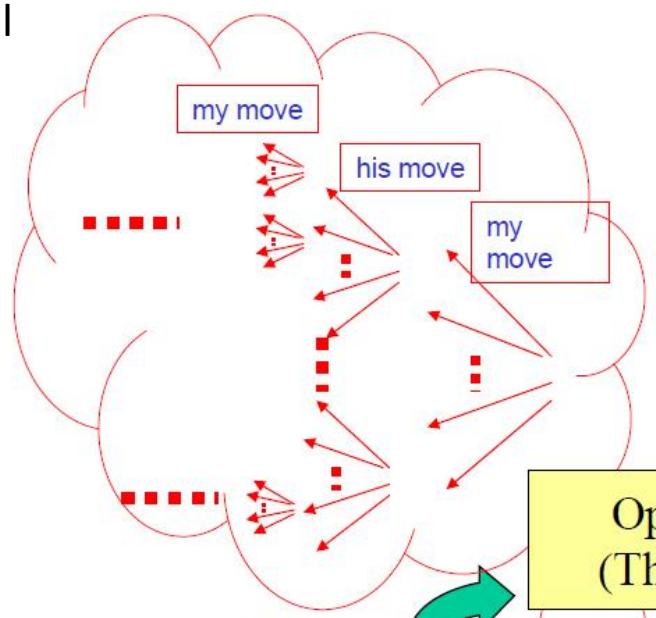
Loser

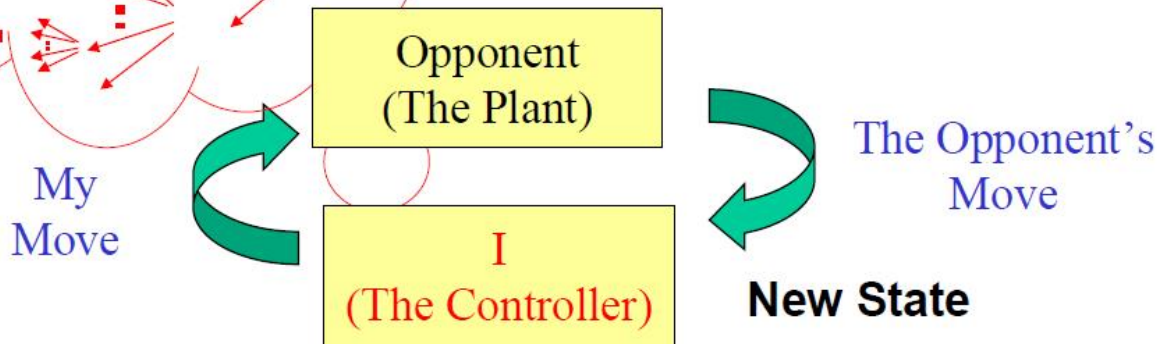
What is MPC? (5/5)

- What objectives the actions were serving?
  - Win in as fewer moves as possible
- Why?
  - Longer, the less probability to win
- Constraints?
  - Play within the chess rul

Important observations

- Prediction was done as many steps ahead required for winning if possible
  - Every move, current and past had an impact on the future of the game
- Prediction was re-done again after every move





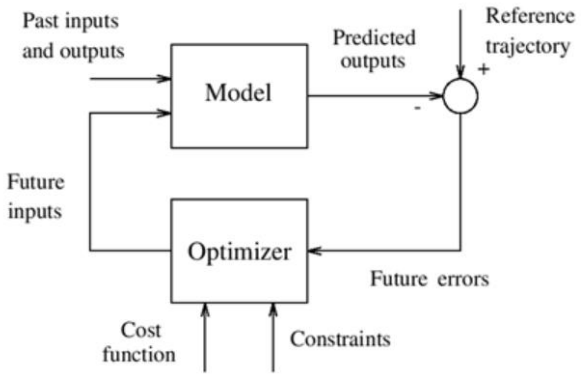
What is MPC (finally?)

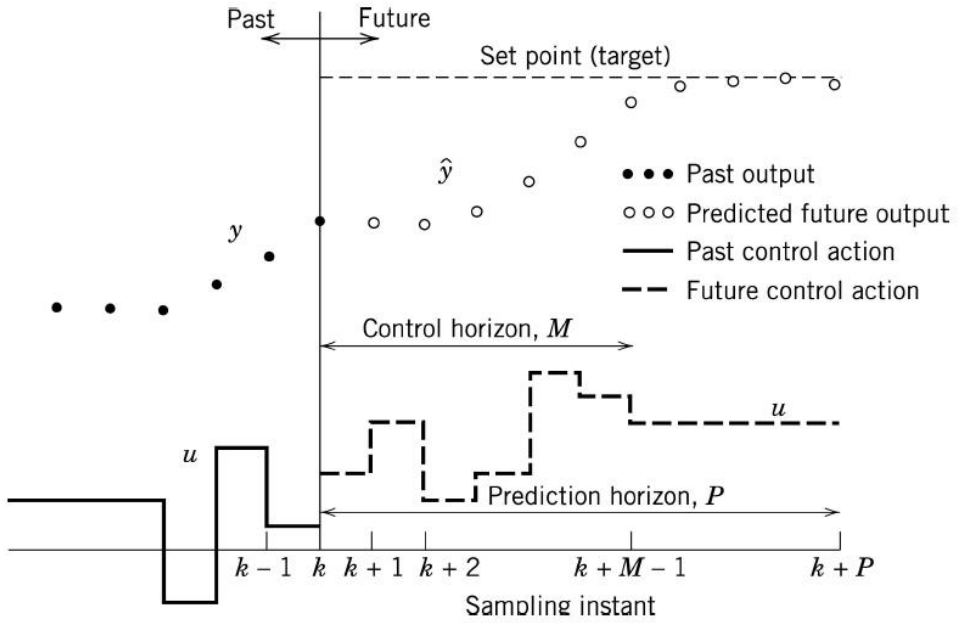
Second definition of MPC:

MPC is a controller which uses prediction that includes the effect of past and future control actions such that to satisfy the desired objectives without violation of constraints but implements only the first time-step action.

KEY ELEMENTS OF MPC

- Prediction Model
  - Effect of past actions onto the future **(implemented)**
  - Effect of current and future actions (**to be implemented**)
- **Objectives** with Constraints to be met on Input action, Output deviations
- Optimizer to obtain the control actions





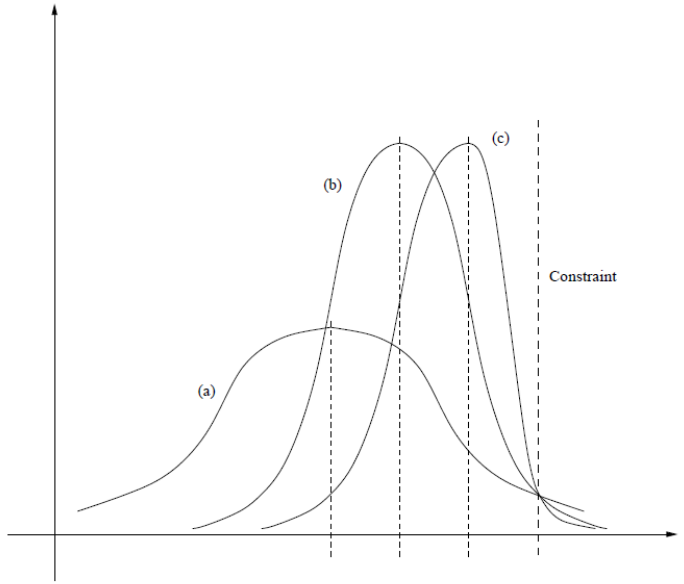
Line in CHESS, Implementing the first step of current move calculations and re-computing the control trajectory at each time step is called Receding Horizon control

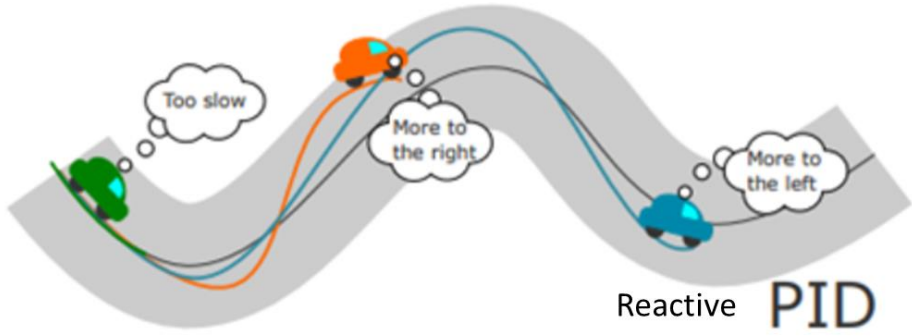
Key advantages of MPC

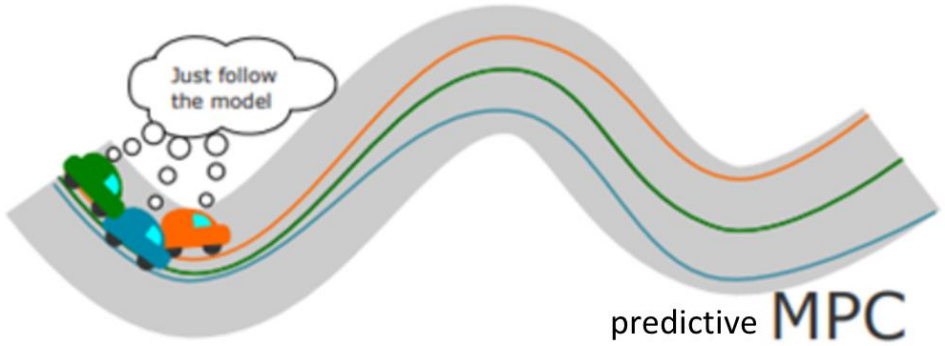
- MPC Controller actions keeps System objectives met as much as possible in real-time by
- Driving the economics closer to optimal without sacrificing safety limits
- Handles constraints on key variables, both on the inputs and outputs

Smoother operations through elegantly addressing interactions through predictions, keeping the variance with target as low as possible

a) Open loop control
b) Classical control
c) MPC

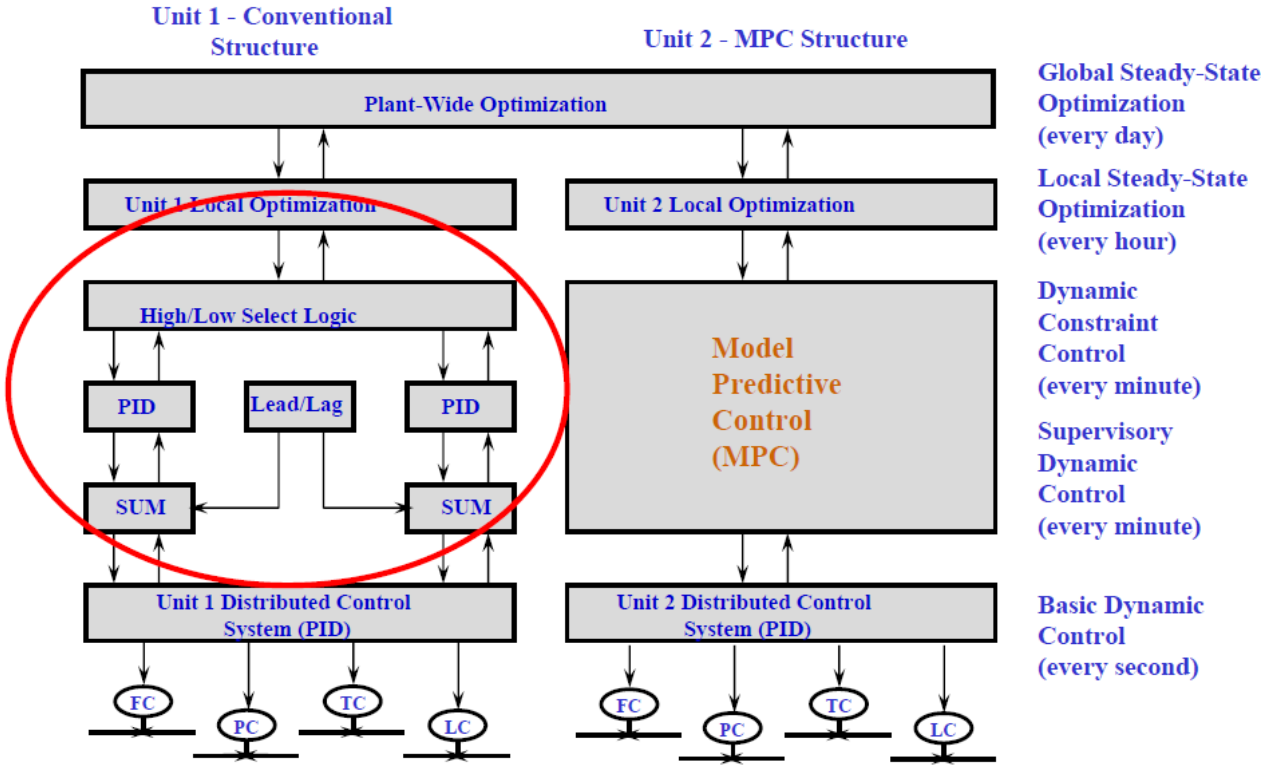


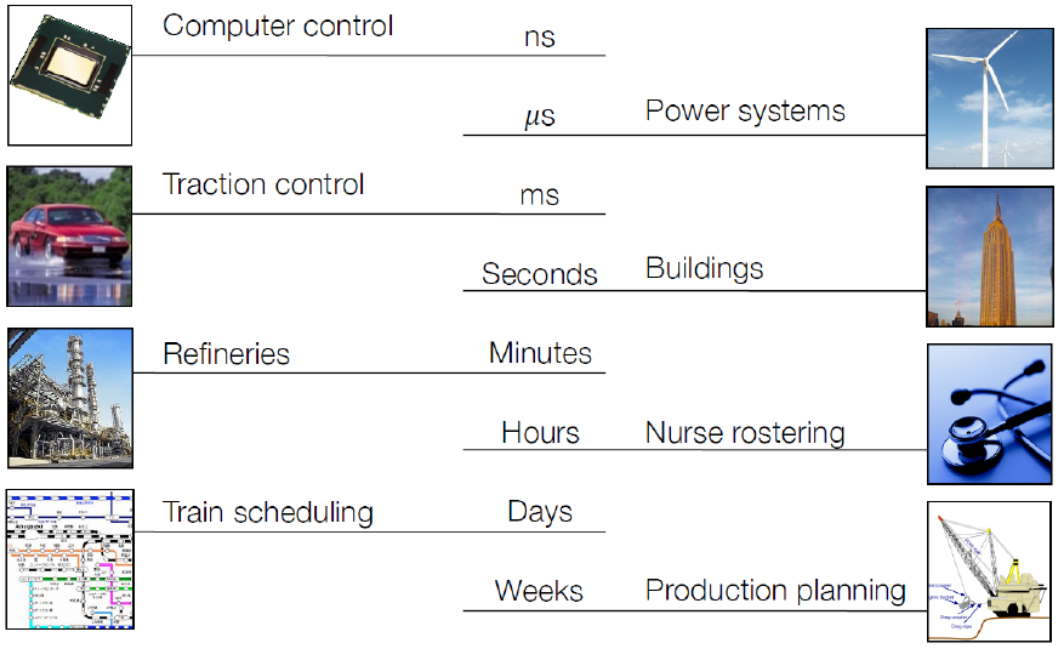




The control pyramid – Role of MPC

Refinery/ Process industry





Important observations

- Computation was limiting the application to Refineries in the 90s (minutes)
- Today - MPC applications operates in few mill-seconds (Cruise control)

Some applications of MPC

- 35+ years in refineries and petrochemicals
- Upcoming fields
- Robotics,
- Cruise control,
- optimizing buffering and quality in video streaming ,
- Path planning – autonomous vehicles

etc

Course organization

- Simulation model types (Impulse, step, state space) - Prediction equations, use of Kalman filter in prediction equation
- Control solution for unconstrained system
- Optimization with constrains
- Degrees of Freedom – steady state optimization
- Industrial MPC implementations
- MPC Tuning parameters and recommendations
- Handling Model plant mismatch – some formulation changes
- Field implementation – Benefit analysis
- Stability aspects
- AI in MPC
- Project

Book: Predictive controls with constraints – J M Maciejowski
Book: MPC system design and implementation using MATLAB – Liuping Wang