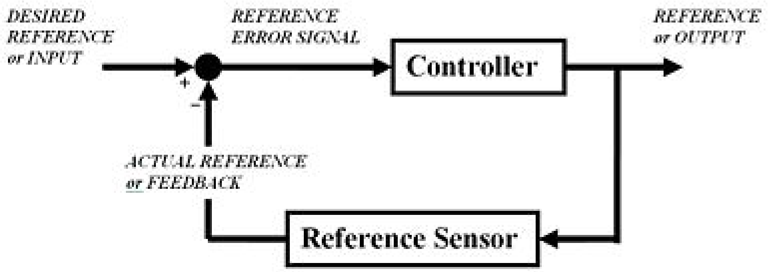
Control Room Accelerator Physics

Supplemental

Introduction to Control Theory I

Outline

1. The big picture
   1. Definition
   2. Context
2. Software process
3. Accelerators and software engineering
4. Application frameworks



Classical Control Theory

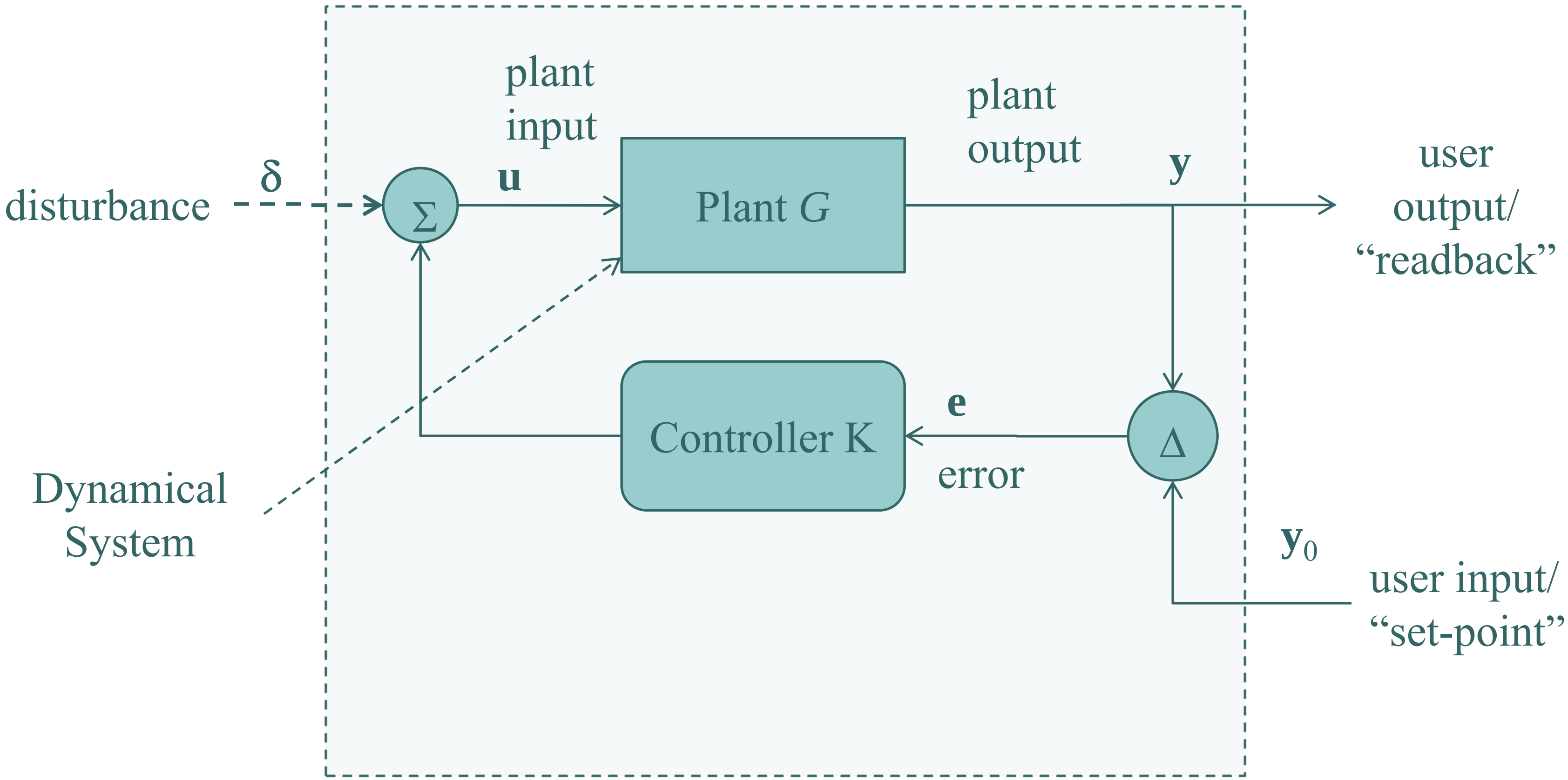
- Feedback control
- Transfer Function based
- 100 year old
- No guarantees on input/output constraints

Modern Control Theory

- 1950/1960
- Can be state space oriented
- Treats uncertainty (robustness)
- Model based control
  - Dynamical systems
  - (Abstract) algebra (Lie)
- Predictive controllers
- What is intelligence?
- Based upon
  - Optimality criteria

Classic "Control"

Output Stabilization /Disturbance Rejection



User viewpoint

Classical Control: PID Feedback

- If the plant is **linear** with known parameters then it can be described by a *transfer function*

$$\mathbf{G}(\mathbf{u}) = \mathbf{G}(j\omega)\mathbf{u}(j\omega)$$

$$\mathbf{G}(j\omega) \in \mathbb{C}^{p\times m}$$

$$\mathbf{u}(j\omega) \in \mathbb{C}^{m}$$

where $j = \sqrt{-1}$ and ω is angular frequency.
(i.e., Laplace transform everything in sight, then set $s=j\omega$)

- **Pick** the control law $\mathbf{u} = \mathbf{K}(\mathbf{y}-\mathbf{y}_0)$, $\mathbf{K} \in \mathbf{R}^{m\times p}$, then

$$\mathbf{G}(j\omega) \in \mathbb{C}^{p\times m}$$

$$\mathbf{u}(j\omega) \in \mathbb{C}^{m}$$

"Feedback Tuning" means finding **K** such that

- $(\mathbf{I}-\mathbf{GK})^{-1}\mathbf{GK}$ is close to unity
- $(\mathbf{I}-\mathbf{GK})^{-1}\mathbf{G}$ is close to zero

Disturbance Rejection

- Feedback "lock"
- Simple control law
  - PID

$$u = k_i \int e\,dt + k_p e + k_d \dot{e}$$

- Most Simple
  - Thermostat
  - Cruise control
  - Governor

Modern Control

- Oriented toward a mathematical description of the control process
  - Actuators: What are my controls (i.e., decisions)?
    - Eg., aileron, magnet PS, prime interest rate
  - Sensors: What are my observables? (What can I see?)
    - Eg., heading (gyroscope), beam position, inflation
  - Constraints:
    - Ranges of my decision variables
    - Range of my sensors
  - Objectives: What do I want to do?
    - Eg., "go to Cleveland", "center the beam", "grow economy"
  - Optimality: The "best" way to achieve my objectives
    - Eg., "cheapest", "least emittance", "minimal unemployment"

Strategy

- Objectives + optimality => strategy
- Military: Tactics
  - Specific actions (decisions with constraints) for achieving objectives in some optimal manner based upon an overall strategy
- Control Theory: Control Laws
  - Specific rules for using actuators (with constraints), typically expressed in terms of the observable quantities and optimality criteria, formulated using an overall strategy.

  - The transfer function is a *tactic*, not a *strategy*

Basic Control Concepts

- Controllability
- Observability
- Stability

- Define basic notions of control theory in words – redefine later rigorously and give examples from linear system theory

Controllability

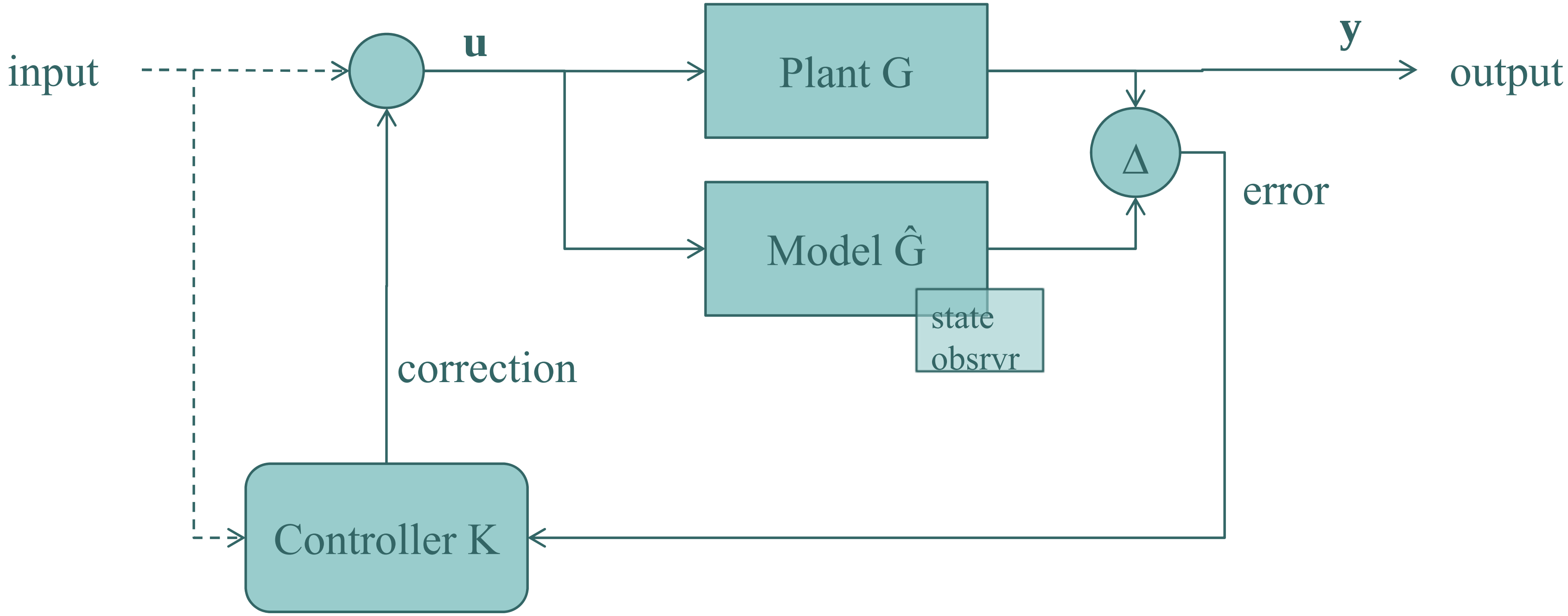
- A plant G is said to be controllable if, given any initial state $\mathbf{x}_0$ and final state $\mathbf{x}_1$, there exists a control $\mathbf{u}(\cdot)$ that will steer the system between the two states.
  - If a plant is not controllable then there exist states in the state space that cannot be reached regardless of the input.

Observability

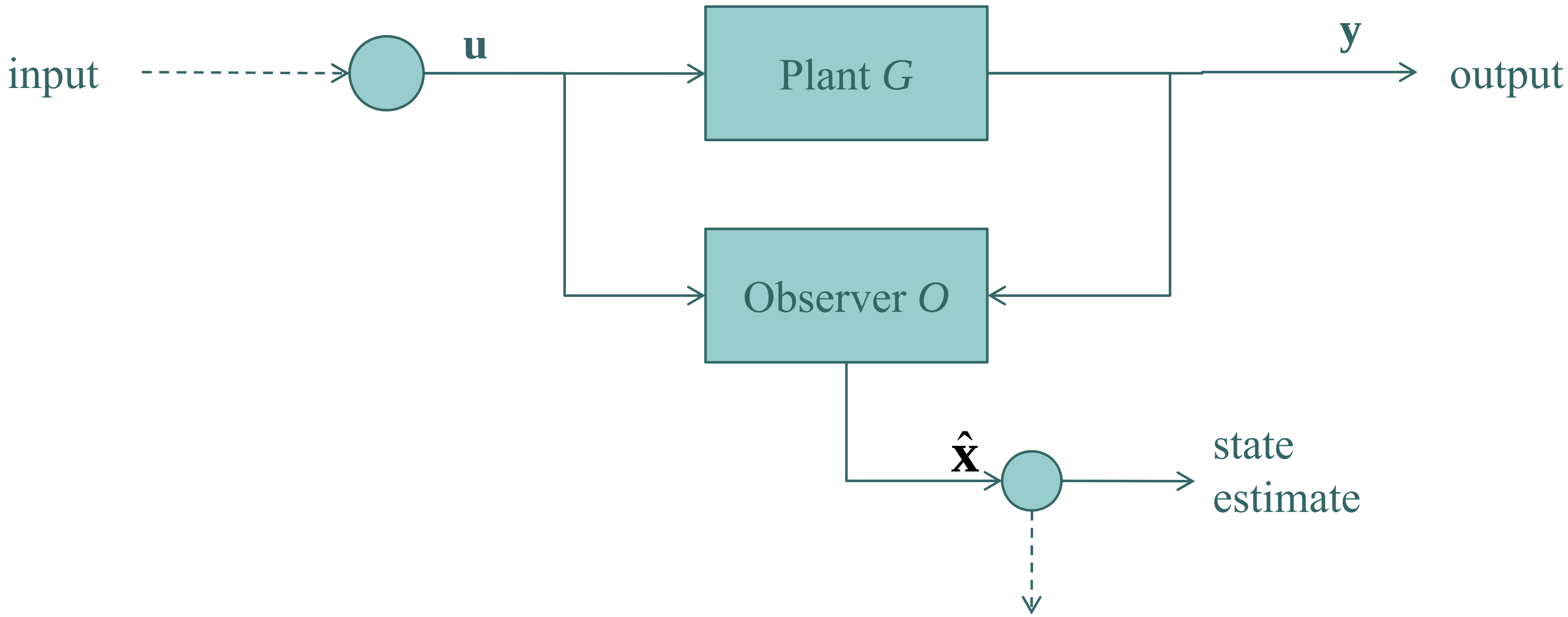
A plant G is said to be *observable* if you can deduce its entire behavior by monitoring the outputs for a finite amount of time.

- If a system is not observable, this implies that the values of some internal states $\mathbf{x}(t)$ cannot be determined by the output sensors.
- Such state values are consequently unknowable to the controller, which then cannot fulfill any specifications referring to these outputs

Model Reference Control



Observers


input
u
Plant G
y
output
Observer O
$\hat{\mathbf{x}}$
state
estimate

Beam Position State Obsver