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Under Control: A Control Theory Introduction for Computer Scientists

Session @ VELVET 2023

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Goal of this tutorial

- Present the need for regulation of computing systems
- Show how computing systems can benefit from the Feedback loop approach
- Show what Control Theory can bring
- Quick presentation of the methodology
- Let you implement some Control Theory controllers!

The need for Regulation

- Complex systems
 - Crazy software stacks on crazy hardware
 - Many sources of unpredictability
 - \leadsto need for dynamic management
- Usual approaches:
 - simple rules
 - *if this then that*
 - very arbitrary constants
 - no guarantee
 - or model as much as possible
 - then solve “optimally”
 - very complex
 - guarantee only if model stands

We need another approach (guarantees + simplicity)

The Feedback Loop

The idea

Use the knowledge about the current state of the system to respond

Autonomic Computing (IBM 2003)

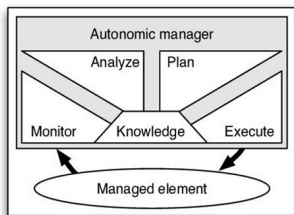


Figure: MAPE-K Loop

- auto-*
 - configuration
 - healing
 - **optimization**
 - protection
- main tool: MAPE-K loop
- Separation of concerns
- ≠ implementations of AC (rules, AI, control)

Some Examples

- Regulate the **heat of a processor** based on its frequency
 - Sensor: CPU thermometer
 - Actuator: DVFS
 - Reference: Desired CPU temperature
- Regulate the **waiting time of users** based on the number of available servers
 - Sensor: Waiting time of a request
 - Actuator: Number of servers to add/remove
 - Reference: Mean waiting time for the requests
- Regulate the **FPS of an online video rendering** based on the quality
 - Sensor: FPS
 - Actuator: depth of computation
 - Reference: 60 FPS

Control Theory

Goal

Act on dynamic system to reach desired behavior with guarantees

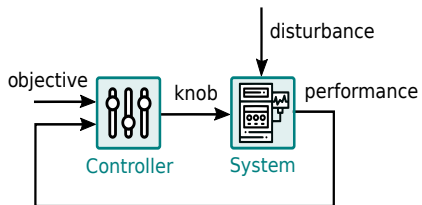


Figure: Control Loop

- Proven Guarantees
 - Stability
 - Robustness
 - Precision
- Long history in physical systems
- Only recent for CS
- Reusable methodology

Methodology

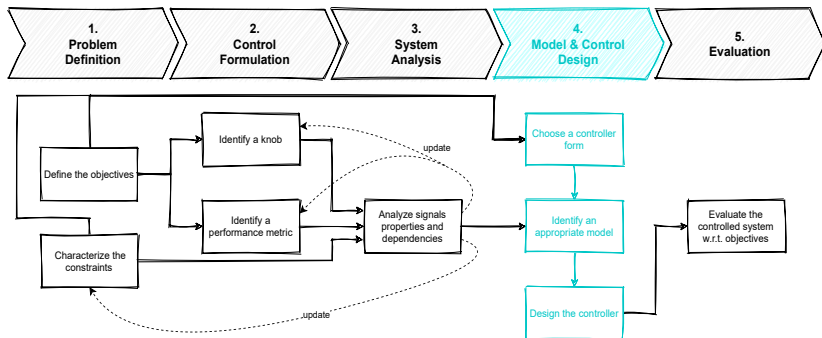


Figure: Control Theory Methodology

The (famous) PID Controller (discretized)

First, a **Model** ... (i.e., how does the system behave (Open-Loop))

$$\mathbf{y}(k+1) = \sum_{i=0}^k a_i \mathbf{y}(k-i) + \sum_{j=0}^k b_j \mathbf{u}(k-j)$$

... then a **PID Controller** (i.e., the Closed-Loop behavior)

$$\mathbf{u}_k = \mathbf{K}_p \times \text{Error}_k + \mathbf{K}_i \times \sum_k \text{Error}_k + \mathbf{K}_d \times (\text{Error}_k - \text{Error}_{k-1})$$

Sensors & Actuators

- Actuator: \mathbf{u}
- Sensor: \mathbf{y}
- Error: *Reference* – *Sensor*

Method

- 1 Open-Loop expe (predefined \mathbf{u})
- 2 Model parameters (a_i, b_j)
- 3 Choice controller behavior (\mathbf{K}_*)

Settling Time, Overshoot and Error

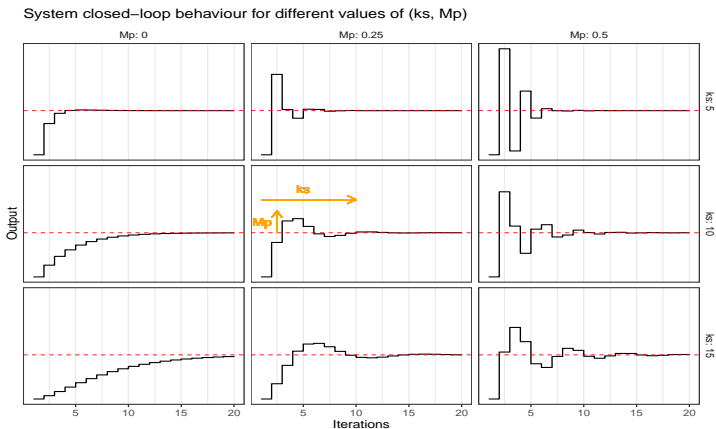


Figure: Closed Loop Behavior

The controller gains define this behavior!

Controllers

Goal

Map the error to the next action to reach desired system state with guarantees

Many (many) types of Controllers

- Feedback (PID, MFC, RST, etc.)
- Feedforward (proactive reaction to disturbances)
- Adaptive (change behavior at runtime)
- Model Predictive
- Event Based
- Optimal
- and more!

Your turn!

What you will do now

- 1 Play with a dummy system
- 2 Implement a naive Threshold-based controller
- 3 First introduction with Control Theory: P Controller
- 4 Implement a more precise controller (PI)
- 5 Perform an identification phase
- 6 **Implement a PI controller on a “real” system**

Starting Point

<https://tinyurl.com/Control4ComputingVELVET>