# Natural Computation and Behavioral Robotics

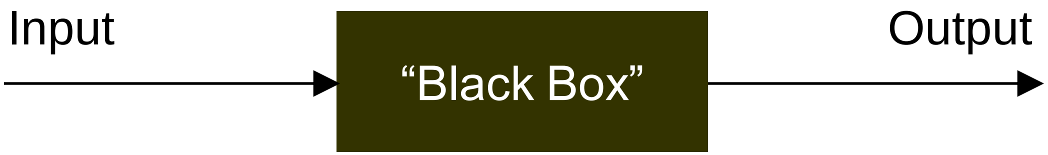
## Elements of Adaptive Automatic Control

# Overview

- What is Signal Processing ?
- What is Automatic Control ?
- Auto-Regressive Moving-Average models
- Open-Loop and Closed-Loop control
- What is Adaptive Automatic Control ?
- Feedback and Feed-forward Regulators
- Adaptive Control and A.I.

# Control and Systems Design

- A system is typically described as a “black box”, i.e. not revealing its internal structure and functionality.
- The behavior of a “black box” module can be studied by systematic correlative measurements between the input and the produced output.
- The analysis can be realized in the time-domain or the frequency-domain, according to each problem.



# Control and Systems Design

Basic procedure:

1. Create a simple input pattern, e.g. a very short "pulse" signal or a "stepping-function" signal.
2. Measure the produced output from the system module, i.e. the "Black Box".
3. Approximate the correlative measurements of input-output profiles by an appropriate model.
4. Use the produced model as a "template" to generate and predict the behavior of the "Black Box" for any given input.

# Control and Systems Design

- Time-Domain Analysis: The exact sequence of the input values is correlated with the exact sequence of the output values.
- Frequency-Domain Analysis: The sequences of the input and output values are translated into a frequency profile (input spectrum) and a frequency response (output spectrum) accordingly, and the system is analyzed in terms of frequency elements.
- Other: Instead of the standard frequency analysis (Fourier), more generalized transformations can be applied to the input and the output signals (e.g. Wavelets, DCT, ...).

# Signal Processing – ARMA

Typical model for ARMA(N,M):

$$\sum_{k=0}^{N} a_k y(n-k) = \sum_{r=0}^{M} b_r x(n-r) \quad \Leftrightarrow$$

$$y(n) = \frac{1}{a_0}\left( \sum_{r=0}^{M} b_r x(n-r) - \sum_{k=1}^{N} a_k y(n-k) \right)$$

**"AR(N)"** : Auto-Regressive, i.e. uses N previous outputs y(.)
**"MA(M)"** : Moving-Average, i.e. uses M previous inputs x(.)
**"ARMA(N,M)"** : combines an AR(N) and a MA(M) together

# Signal Processing – ARMA

- ARMA(N,M) models are very generic in form, they can model any system that uses M previous inputs and/or its own N previous outputs to produce the next output.
- All standard ARMA models are linear, i.e. they include input and output terms in the 1st order.
- They are also used as the base model for frequency-based analysis and design of control modules (digital filters, controllers, etc.)

See also: Auto-regressive **Integrated** Moving Average ("ARIMA") models

# Automatic Control

Basic approach:

- Filtering Problem: Create an approximation model for a "Black Box" and use it to predict its behavior for any input (transformation).
- Control Problem: The "Black Box" model can be used in reverse mode, i.e. to calculate the appropriate input in order to produce a desired output (adaptation).

# Automatic Control

- In the Control Problem, the “output” can be the result of a machine or equipment in a physical process, while the “input” is the appropriate command to produce the desired functionality.
- Example: In an Automatic Pilot Module, the “output” is the aircraft’s attitude (position, speed, etc), while the “input” is the control commands that a human pilot should give through the cockpit, in order to produce the desired “result” (e.g. land the plane).

# Open-Loop and Closed-Loop

- Open-Loop Control: A specific "reference point" is used to calculate the required action (correction step) based only on this fixed value and the current input.
- Closed-Loop Control: A specific "optimal condition" is used to define the system's "optimal" behavior and the required action (correction step) is based on the current input **and** the system's own produced output in the previous steps.

Note: In Open-Loop control the correction is calculated upon the input and the "Black-Box" model only, while in the Closed-Loop the actual output of the "Black-Box" model is sent back as an additional correction factor ("**feedback**" input).

"PID" controller = Proportional – Integral – Derivative (model)

# Adaptive Automatic Control

- A typical automatic control model is able to produce the correct "result", as long as the system is stationary, i.e. as long as the conditions and the environment stays the same ($\rightarrow$ the design is valid).
- Instead, if the environment changes then the model has to be re-designed in order to conform to the new specifications of the "Black Box".
- If this is too complex or too costly to do by a "generic" design, or if such changes are very frequent, the system has to be able to do it by itself (self-adjustment).

# Adaptive Systems – Taxonomy

Class-I: “Feedback Regulators with **no** Memory”

Use only current deviation from desired output to correct itself in the next cycle.

$$x(n+1) = x(n) + error\{y(n),y(n-1)\}$$

Class-II: “Feedback Regulators **with** Memory”

Use N previous traces of the “correction” steps in order to produce a better (future) adjustment.

$$x(n+1) = x(n) + error\{y(n),y(n-1)\} + error\{y(n-1),y(n-2)\} + \ldots$$

# Adaptive Systems – Taxonomy

Class-III: “Feed-forward Regulators with **no** Memory”

Predict the next deviation from desired output to correct itself in the current cycle.

x(n+1) = x(n) + pred.error{y(n+1),y(n)}

Class-IV: “Feed-forward Regulators **with** Memory”

Predict based on N subsequent traces of the “correction” steps in order to produce a better (future) adjustment.

x(n+1) = x(n) + pred.error{y(n+1),y(n)} + error{y(n),y(n-1)} + ...

# Adaptive Control and A.I.

- The behavioral model of an “intelligent” autonomous agent can be viewed as a “Black-Box”.
- Inputs are sensor measurements (smell, hear, see) and internal states/properties (energy, attitude).
- Outputs are actions that lead to “better” states.
- A control model can be designed to approximate an “optimal” behavioral pattern, i.e. a good “Black-Box”.
- If environment changes around the agent, the design process must be continuous, i.e. the control model must be adaptive (self-correcting).

# Food for thought

- When should we use Adaptive AI ?
- When should we use Feedback or Feed-forward Regulators ?
- Do animals employ similar Adaptive AI ?
- How do the ARMA(N,M) models relate to the typical taxonomy of the Adaptive Systems ?
- In what real-world cases these control models are too “simplistic” and inadequate ?

# P.C. – Readings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