BME 5742 Bio-Systems Modeling and Control

Lecture 2

Course Introduction

What is a “Model”?

- Typically it is a set of coupled nonlinear ordinary differential equations
- Some models involve partial differential equations
- Some models involve algebraic equations, side by side with differential equations
- Some models involve random terms
- Models usually involve constraints.

Complex Models

- An accurate description of the behavior of a complex system lies in its detailed parametric interactions.
- Available simulation tools can handle models with large number of states and parameters.
- Most mathematical models of physiological systems require gain coefficients and rate constants, but many of which are unknown, and may even not be measurable.

Reduced Models

- We are forced to simplify the model or reduce the order and complexity of the model, so that the simplified model somehow fits the data that can be measured.
- By reduction we may possibly be missing some interesting system behavior features characterizing the nonlinear complexity.
- On the other hand, high order models often have initialization problems and dependency among variables.

Homeostasis

- Physiological systems are generally self-regulatory closed-loop systems.
- "Homeostasis" (Cannon): Maintenance of specific (narrowly ranged) steady-state conditions, at the cell level and organism level
- It is a result of many <u>negative feedback loops</u>

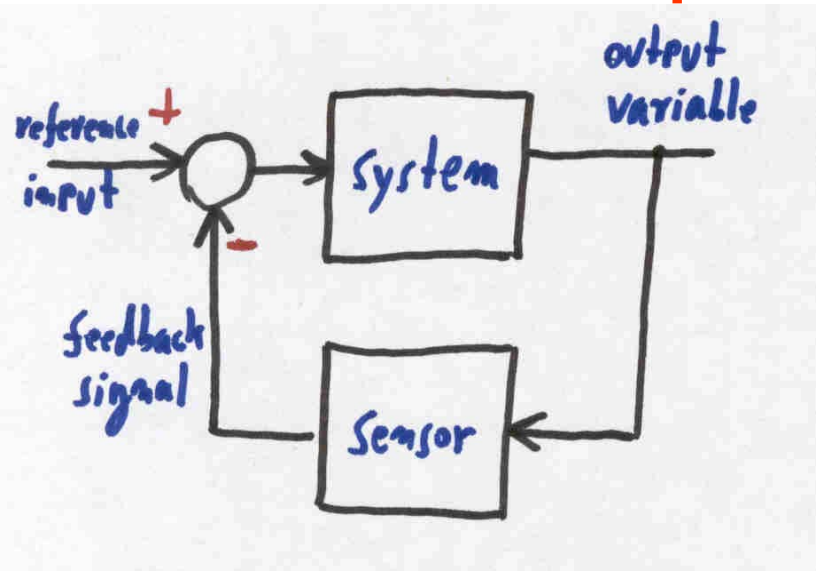
Internal Feedback Control

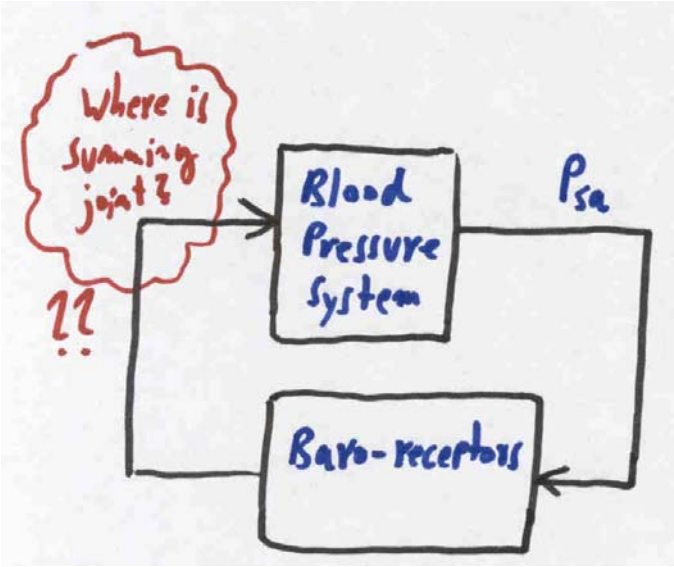
- Regulator: a negative feedback loop needed to stabilize a specific variable at a specific desired level, despite (possibly large) external and internal influences.
- Every regulated variable must be measured to form a feedback signal.

Examples of parameters under homeostatic maintenance

- Body temperature
- Calcium ion concentration in the blood
- Blood glucose concentration
- Mean arterial blood pressure

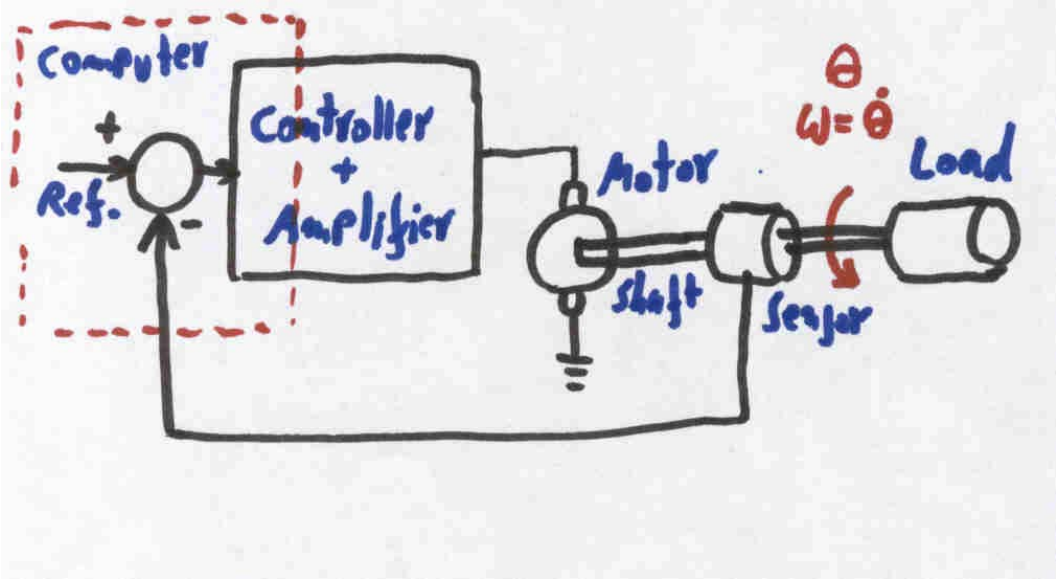
Example: Regulation of arterial blood pressure P_{sa}





- In any negative feedback control system, the variable that is being <u>measured</u> (for signal to serve as a feedback) is the one that is <u>regulated</u>.
- Here, the baroreceptors measure P_{sa} and therefore the value of P_{sa} is regulated to be equal to a suitable reference level.

Engineering Example: Position or Velocity Control of an Electric Motor



- If motor's angular position is sensed (using a potentiometer or optical encoder) then voltage reference determines a desired final angle.
- If motor's angular velocity is sensed (using a tacho-generator) then reference determines a desired final velocity.

Some Properties of Physiological Regulators and Control Systems

- Loops exhibit interactions and cross-coupling, making the whole system multi-input / multi-output [Examples: shared nervous system pathways, hormone affecting more than one class of cells]
- Control is typically done parametrically, through modification of system coefficients, and not by additive control signal. [Example: Hormone affecting diffusion coefficients or reaction rates]

Some Properties of Physiological Regulators and Control Systems

- Every loop contains significant time delays [Examples: Finite transport time that it takes nerve impulses to propagate, Time that it takes a hormone to activate a multi-step biosynthetic pathway]
- Despite the delays, loops are typically stable due to the low loop gains.

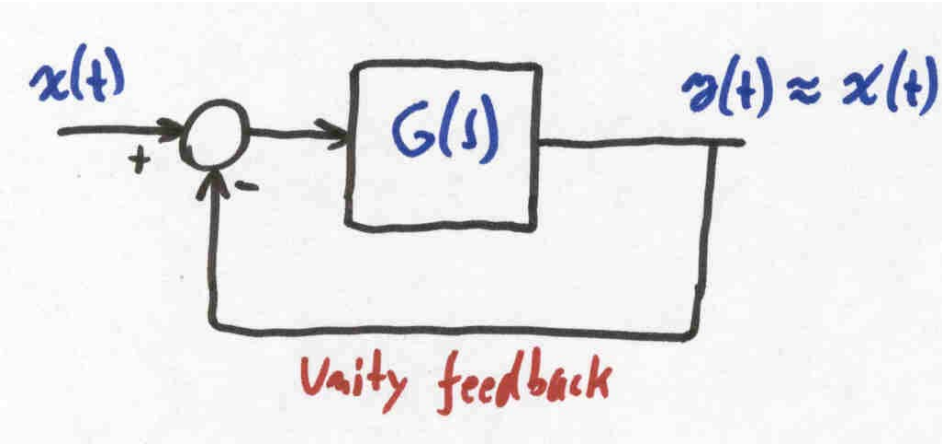
Some Properties of Physiological Regulators and Control Systems

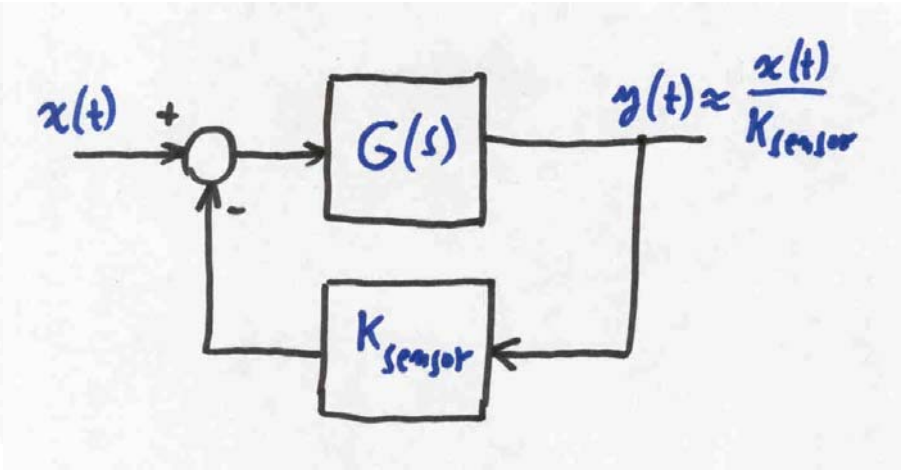
- Almost all such processes are nonlinear [Examples: There are no negative concentrations or negative hormone release rates, Saturation levels of any variable, Multiplication of variables – kinetic rate that depends on the product of reactants' concentrations, Dead-zones – some processes occur only if signal is larger than certain activation level]

Some Properties of Physiological Regulators and Control Systems

- Some processes are massively parallel as every organ is composed of hundreds of thousands of cells that have similar functions → Redundancy, Robust behavior
- Regulation may be uni- or bi-directional [example to push-pull action: Hormone Insulin causes blood glucose to lower, Hormone Glucagon causes blood glucose to rise]
- No uniquely identifiable “summing points”

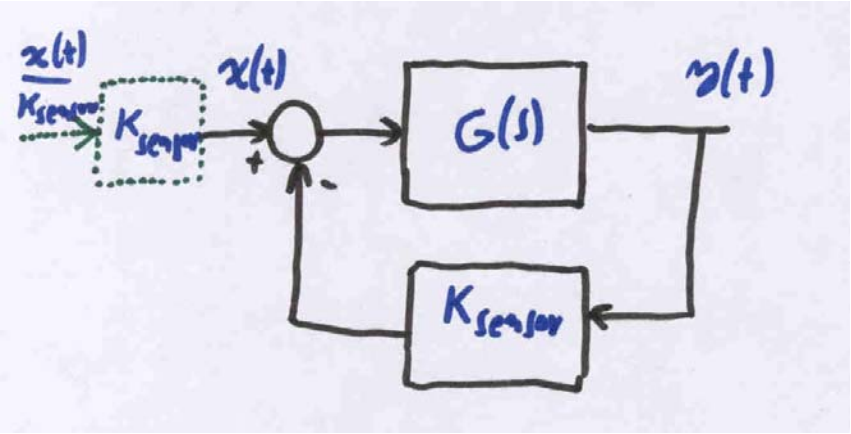
How is the reference input determined? An engineering view:

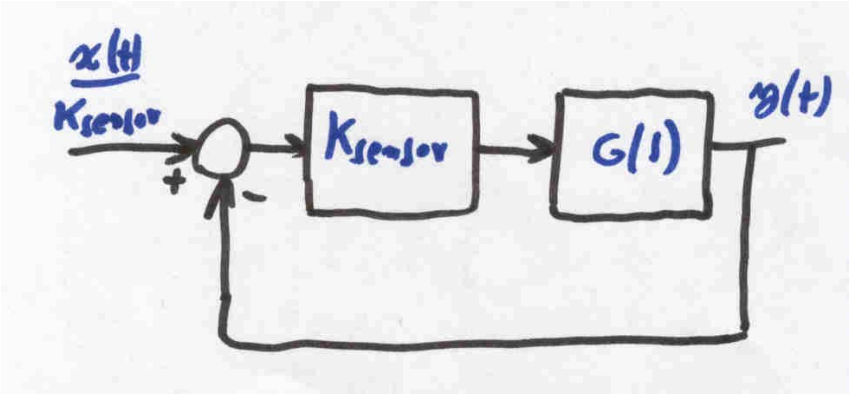




- Engineered control system usually contain a well defined summing joint, where feedback signal is subtracted from the reference input.
- Due to sensor's gain, the true reference level is a scaled version of the actual input signal.

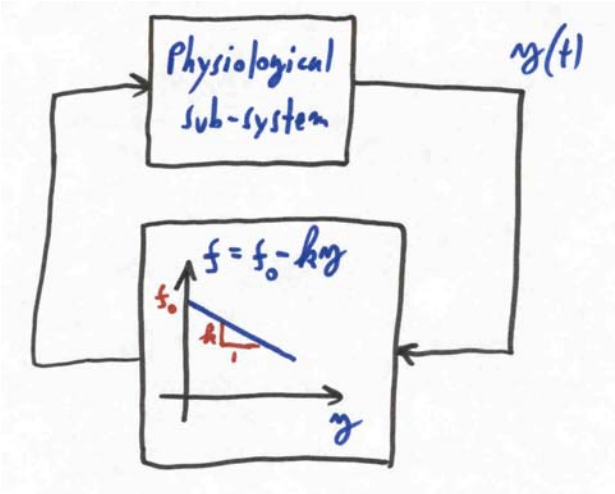
Why does output follow an input scaled by the sensor's gain?

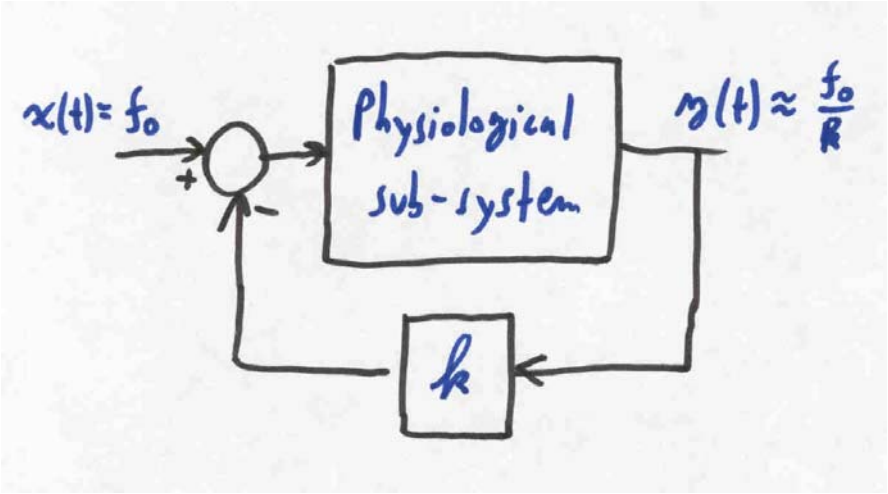




- Create a "dummy" sensor gain block processing the incoming input.
- Merge the two K_{sensor} into a single block operating on the error signal.

How is the reference input determined? A physiological view:





- Most physiological control system lack a well defined summing joint.
- Both – reference level and the negative feedback summation, are obtained due to the monotone decreasing function of the signal that relates to the feedback-sent variable.