Biological Systems
Modeling & Simulation ②

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Previous Lecture

- Biomedical Signal examples (1-d, 2-d, 3-d, …)
- Purpose of Signal Analysis
- Noise
- Frequency domain (1-d, 2-d)
- Filtering unwanted frequencies
- Sampling
- Kalman Filter
- Recursive Algorithm

Biological Signals

- Amplitude limited
- Distorted by colored noise
- Limited length
- Non-stationary
- The underlying system is unknown

Why do we need models?

Insight

- Understanding the underlying system
- Testing bed for several hypotheses

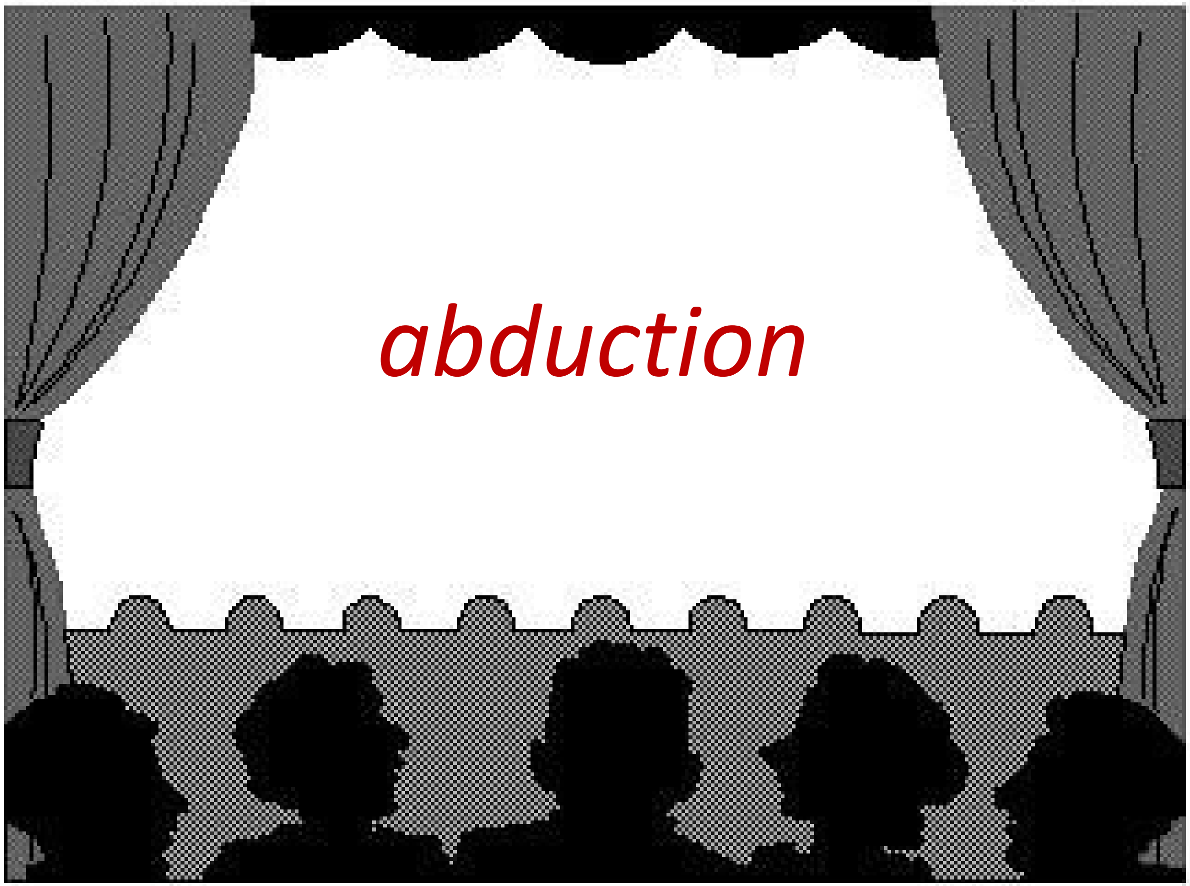
Description

- Design verification
- Explore linear behavior / non-linear nature of the biological physics (going beyond human senses)

Control

- Predictions
- Functional limits

Definition of a Model



Difficulties

1. No access to the unconditional truth
2. No unbiased observer
3. Personal opinion on a hypothesis (abduction)
4. Abduction is not an infallible way for discovering truth

Modeling a System

- System

(a collection of interconnected processes)

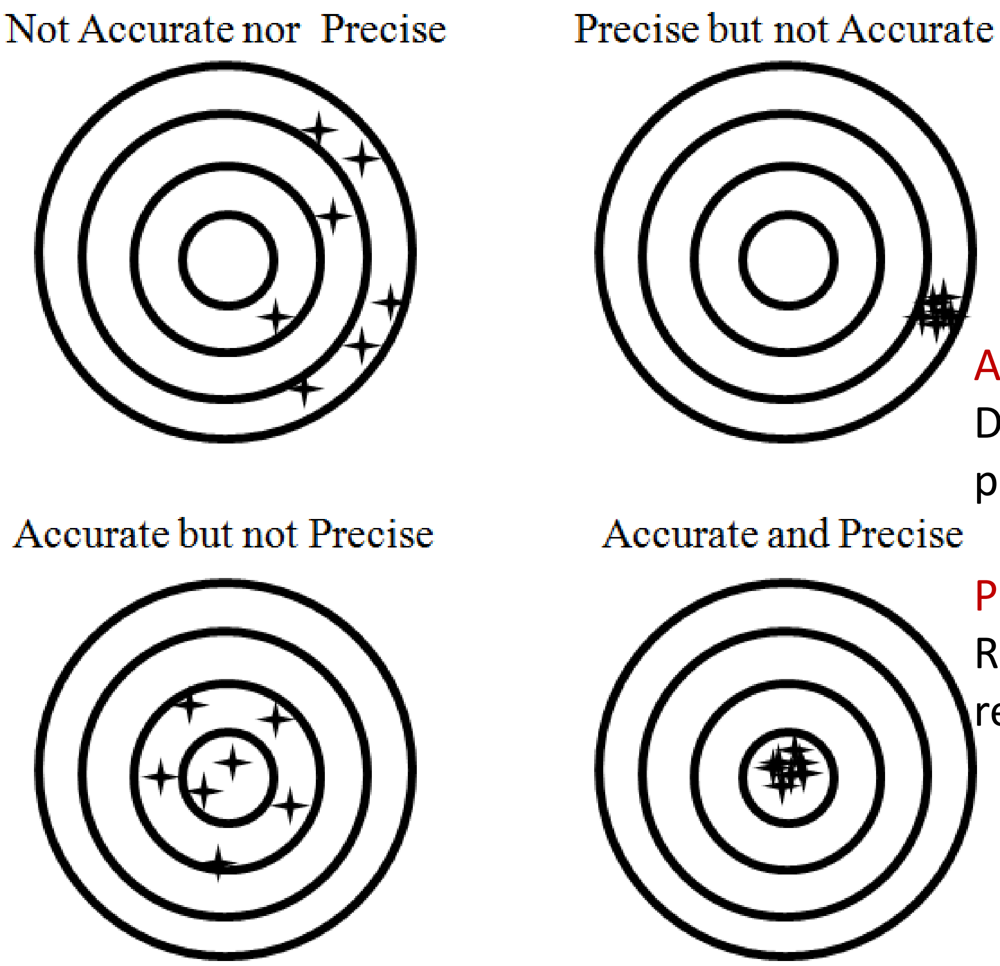
- Model

(a representation that approximates the behavior of an actual system)

- Simulation

(puts the model to work)

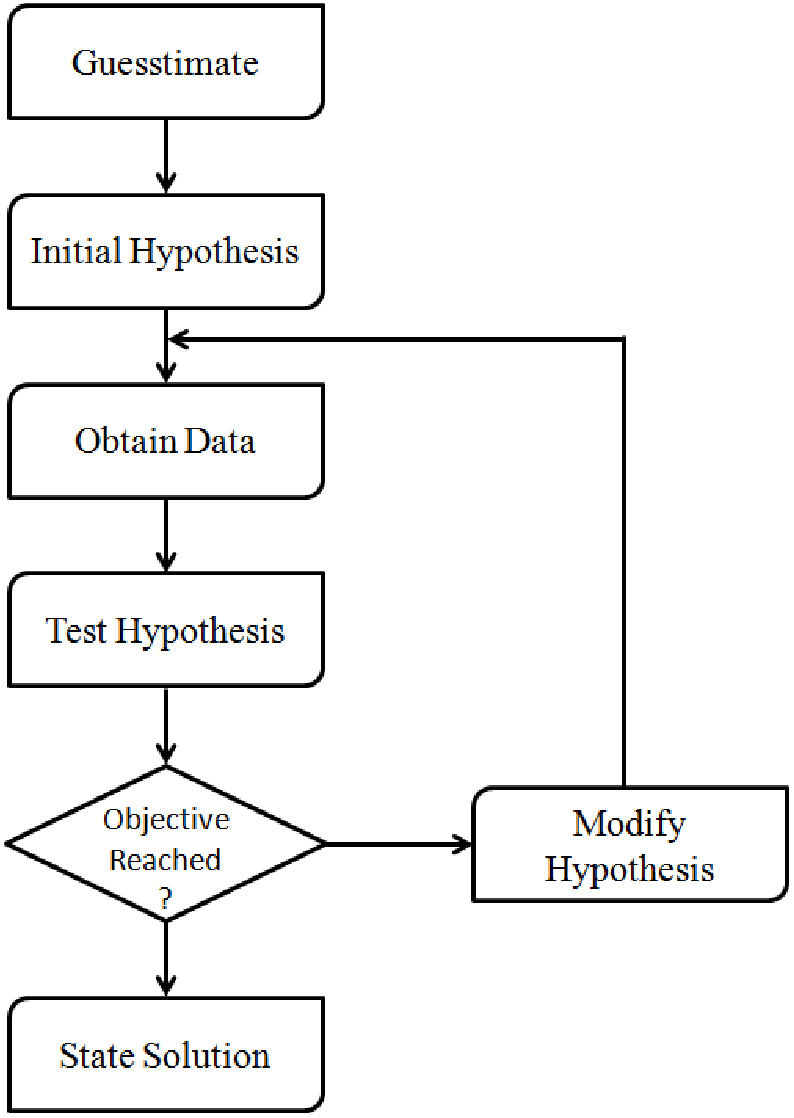
Goodness of a Model



Accuracy
Difference between predicted and true value

Precision
Reproducibility of the results

Model refinement



Classification of Models

Level	Sub-cellular	Cellular	Intercellular	Tissue	Organ	Organism
Behavior		Dynamic			Static	
Chance		Deterministic			Stochastic	
Parameters		Parametric			Non-parametric	
Compartments		Single Compartment			Multiple Compartments	
Linearity		Linear			Non-Linear	
Domain		Time			Frequency	

Linear Modeling of Physiological Systems

Why linear?

- Simple to implement
- Powerful analysis tools

Transforming input into output

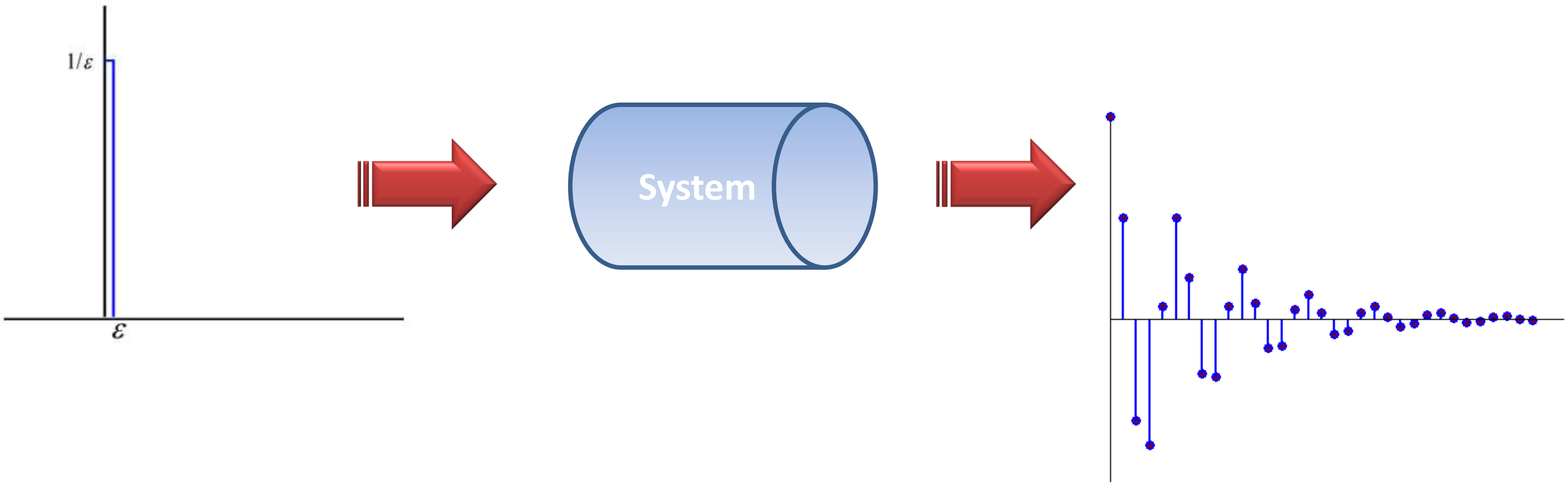
- Time variant
- Time invariant

Linear Time-invariant Systems

1. Superposition
2. Impulse Response of a system

- Testing for linearity may be done using the principle of superposition (e.g. same input at different amplitudes)
- Response of a linear system to a sinusoidal input is a sinusoid at the same frequency
- Linearity of a system means nothing without its range

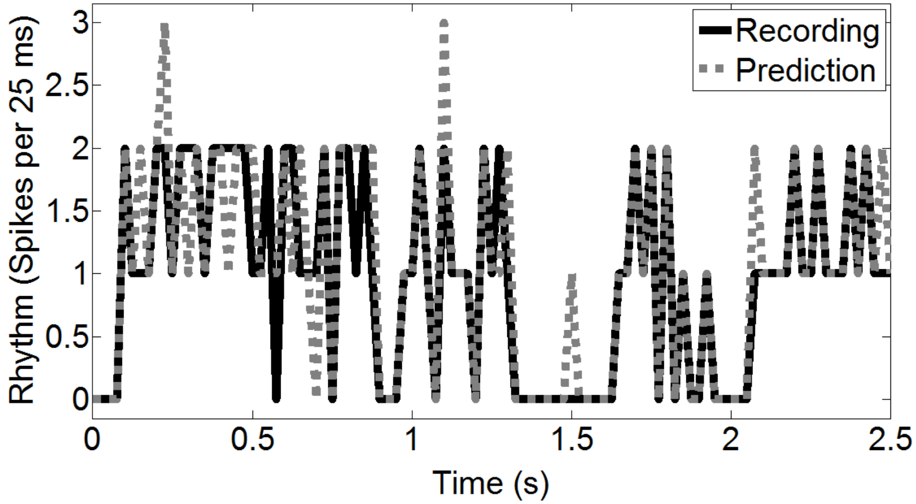
Impulse Response Function

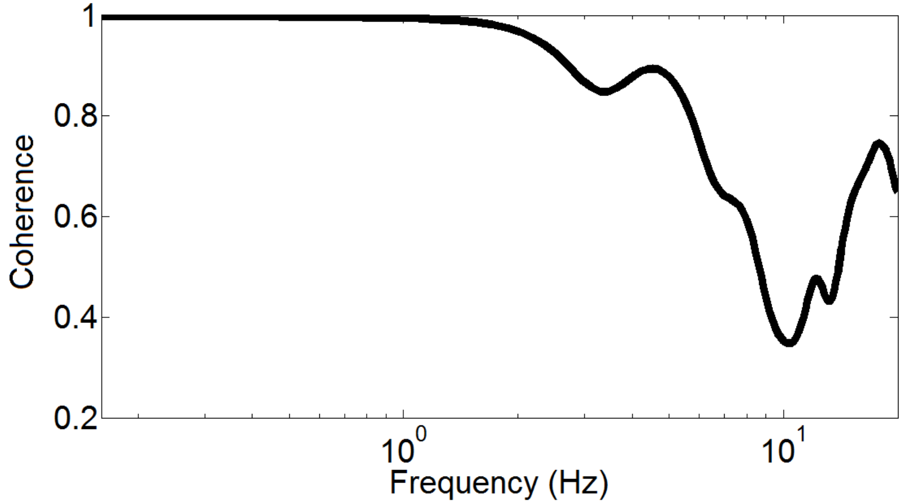


Negative Values = System anticipation
Positive Values = System memory

Living systems frequently demonstrate predictive behavior (e.g. visual pursuit)

Coherence





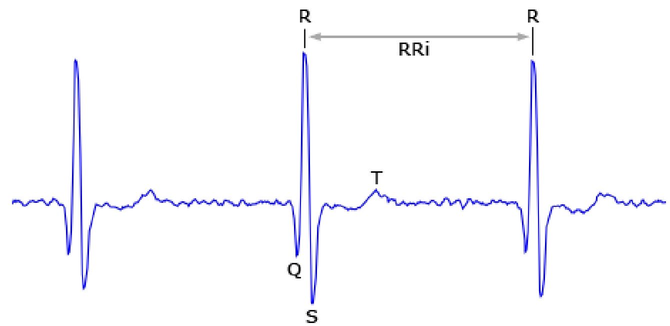
If Coherence is greater than 0 but not 1:

1. Extraneous noise is present in the measurements.
2. The system is not linear.
3. Output is due to the input as well as to other inputs.

Modeling Chaos in Physiology

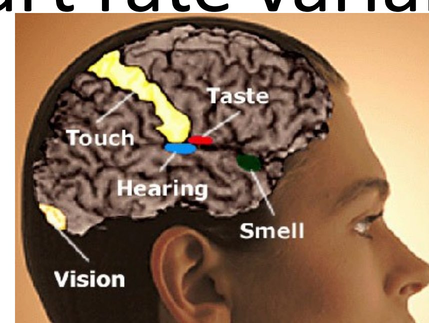
- Chaos (*χᾶος*) = preponderant of all the others
- Physiological Systems are extremely complicated deterministic systems for their observers
- Stochastic determinism observed in biological signals (extraordinary sensitivity to internal conditions)
- Presence of order under the absence of periodicity (strange attractor)
- A chaotic system is not necessarily complex

Chaos in Physiological Systems



Chaos in the heart

- Sinoatrial Node
- Sympathetic & parasympathetic fibers & respiration rate → heart rate variability



Chaos in the brain

- Neuron doctrine
- Feedbacks → internal uncertainties are amplified over time

Why Chaos?

- Better adaptation capabilities

(e.g. heart pumps blood in various circumstances)

- Adaptation in the brain = learning

A never seen before stimulus in the brain, moves the brain to an un-patterned chaotic state.

- Chaos = normal function

  Disease = acute attack of order against chaos

(e.g. the amount of chaos in the Parkinsonian brain decreases as neurons become more synchronized)