Lecture 1

- System Identification
- System
- Model
- The system identification procedure
- Course outline

System Identification

Def. System identification is the field of modeling dynamic systems from experimental data.

- System identification is as much an art as a science.
- Many software packages are available.
- Dates back to Gauss (1809). Birth-year for modern identification theory 1965 (Åström and Bohlin, Ho and Kalman).

System

System (S): A defined part of the real world. Interactions with the environment are described by inputs, outputs and disturbances.

Dynamic system: A system with a memory, i.e., the input value at time $t$ will influence the output at future time instants.

Figure 1: Schematic picture of a system.

Ex. A Solar Heated House
**Ex. Speech**

![Diagram of speech generation](image)

**Models**

*Model (M)*: A description of the system. The model should capture the essential information about the system.

<table>
<thead>
<tr>
<th>Systems</th>
<th>Models</th>
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</thead>
<tbody>
<tr>
<td>Complex</td>
<td>Approximative (idealization). Should capture the relevant information.</td>
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<tr>
<td>Building/Examine systems is expensive, dangerous, time consuming, etc.</td>
<td>Models can answer many questions about the system.</td>
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**Applications**

- Process design. Ex. Designing new cars, new airplanes.
- Control design. Simple regulators ⇒ simple models, and optimal regulators ⇒ sophisticated models.
- Prediction. Forecast the weather, predict the stock market, etc.
- Signal processing. Ex. Communication, echo cancellation.
- Simulation. Ex. Train nuclear plant operators, try new operation strategies.
- Fault detection.

**Types of Models**

- Mental, intuitive or verbal models. Ex. Driving a car.
- Mathematical models. Ex. Differential and difference equations, which are well-suited for modeling dynamical systems.
**Mathematical Models**

- **Analytical models.** Basic laws from physics are used to describe the behavior of a phenomenon.
  - You need to be an expert in the field. Know the physics.
  - Yields physical interpretation.
  - The models are often quite general. Often nonlinear.
- **System identification.** Experimental approach.
  - Black-box models (konfektionsmodeller). Choose a standard model and adjust its parameters to the data.
    - Easy to construct and use.
    - Less general. Often linear.
  - Grey-box models (skräddarsydda modeller). Derive the model and adjust its parameters to the data.
    - Combines analytical modeling and black-box identification.

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**Ex. Models**

- Nonlinear versus linear
- Time continuous versus time discrete
- Deterministic versus stochastic.

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**The System Identification Procedure**

1. Collect data (*experiment design, \( X \)*). If possible choose the input signal such that the data become maximally informative. Reduce the influence of noise.
2. Choose the **model structure** \((M)\). Use priori knowledge and engineering intuition. Most important and most difficult step. (Do not estimate what you already know).
3. **Identification method** \((I)\). Determine the best model in the model structure (find optimal \( \theta \) using e.g., the least squares method).
4. **Model validation.** Is the model good enough? Good is subjective, and depends on the purpose with the model.
Typical problems to answer

- How to design the experiment. How much data is needed?
- How to choose the model structure?
- How to deal with noise? Data contains noise, hence the measurements are unreliable.
- How do we measure the quality of the model.
- How will the purpose of the model affect the identification?
- How do we handle non-linear and time-varying effects?

Course Outline

- Non parametric methods, input signals, model structures.
- Parametric methods. Linear regression (the least squares method), prediction error methods, instrumental variable methods.
- Model validation.
- Recursive identification.
- Identification in closed-loop.
- Practical aspects.

System Identification Methods

- Non parametric methods. The results are curves, tables, etc. These methods are simple to apply. They give basic information about, e.g., time delays and time constants of the system.
  - Ex. transient analysis (impulse or step responses) and frequency analysis (input is a sinusoid).
- Parametric methods. The results are the values of the parameters in the models. These methods can handle disturbances and they provide better accuracy. They are often computationally more demanding.

Conclusion

- System identification is the art of building mathematical models of dynamical systems from experimental data. It is an iterative procedure.
  - A real system is often very complex. A model is an approximation.
  - Data contain noise, hence the measurements are unreliable.
- Analytical methods versus system identification (black-box, grey-box)
- Non parametric methods versus parametric methods.
- Procedure: Collect data, choose a model structure, determine the best model within the model structure, validation.
An Example

Identify a hairdryer: air is fanned true a tube and heated at the inlet. Input $u$: power of the heating device. Output $y$: air temperature.

```matlab
>> load dryer2
>> z2 = [y2(1:300) u2(1:300)];
>> idplot(z2, 200:300, 0.08)
```

Nonparametric modeling:
```
>> z2 = dtrend(z2);
>> ir = cra(z2);
>> step = cumsum(ir);
>> plot(step), ...
```

Parametric modeling: ARX model,

$$y(t) + a_1 y(t-1) + a_2 y(t-2) - b_1 u(t-3) + b_2 u(t-4)$$

```matlab
>> th = arx(z2, [2 2 3]); th = sett(th, 0.08);
>> u = dtrend(u2(800:900)); y = dtrend(y2(800:900));
>> yh = idsim(u, th);
>> plot([yh y]), ...
```

Pole zero plot of the model:
```
>> zpch = th2zp(th);
>> zpplot(zpch)
```
Compare the transfer functions obtained from nonparametric and parametric modeling:

```matlab
>> gth = th2ff(th);
>> gs = spa(z2); gs = sett(gs, 0.08);
>> bodeplot([gs gth])
```

![AMplitude Plot](image_url)  
![Phase Plot](image_url)