Massachusetts Institute of Technology
Department of Mechanical Engineering

2.141 Modeling and Simulation of Dynamic Systems

INTRODUCTION

GOAL OF THE SUBJECT

Methods for mathematical modeling of engineering systems

- **Computational approaches are ubiquitous in engineering**
- **They all depend upon a mathematical representation**
- **Formulation of an *appropriate* mathematical model is essential**
- **—the critical link between analysis and engineering reality**

FOCUS OF THIS COURSE

The *modeling process*

- **—a systematic approach to formulating practical mathematical models of physical systems**

MULTI-DOMAIN MODELING

ENGINEERING SYSTEMS ARE BECOMING PROGRESSIVELY MORE INTEGRATED

- **They involve interactions between phenomena in different engineering domains**
- **They depend on strong coupling between**
  - **electronics**
  - **mechanics**
  - **fluid flow**
  - **thermal processes**
  - **chemical processes**
  - **etc.**
- **Requires a multi-disciplinary approach covering each of these domains**

INTEGRATED MODELS OF MULTI-DOMAIN BEHAVIOR REQUIRE SPECIAL CARE

- **—modeling assumptions that appear reasonable in one domain can be problematical in others**

ENERGY-BASED APPROACH

THE CENTRAL THEME OF THIS COURSE:

a multi-disciplinary, integrated approach to modeling physical system behavior in different engineering domains

The course will present an *energy-based* approach

We will make extensive use of bond graph notation

SIMPLIFIED MODELS

- **Developing models is the goal of much of engineering and most of science**
  - **We’re not (quite) that ambitious**

OUR AIM:

- **Simplified models of physical system dynamic behavior**

SIMPLICITY VS. COMPETENCE

- **Competence: how faithfully a model represents important physical system behavior**
  - **"Important behavior" is defined by context**
  - **We will use control system design and implementation for context**
  - **The methods are relevant to many other engineering applications**

WHY CONTROL SYSTEMS?

- This application provides a natural incentive for model simplicity
  - Design, implementation and operation of control systems leans heavily on mathematical models
    - Design (e.g., LQG, pole-placement)
    - Measurement (e.g., Kalman filter)
    - Control (e.g., adaptive)
    - Diagnosis (e.g., fault identification)
  - Model complexity directly affects cost and performance

NETWORK MODELS

- **Continuing advances in computer technology permit mathematical models of increasingly finer detail**
  - **—but this is not without cost**
- **Fine-grained models may improve numerical predictive accuracy**
  - **but fine-grained models may obscure insight**

INSIGHT IS THE MAIN GOAL OF MODELING

- **Our goal will be a state-determined representation**
  - **the point of departure for modern control system design analysis and implementation**
  - **finite number of state variables**
- **Therefore we will use networks of elements**
  - **a generalization of familiar circuit models**

$$d\mathbf{x}/dt = f(\mathbf{x},\mathbf{u},t)$$

$$\mathbf{y} = g(\mathbf{x},\mathbf{u},t)$$

$$\mathbf{x} \in \Re^n, \mathbf{u} \in \Re^m, t \in \Re^1, \mathbf{y} \in \Re^r$$

COURSE OUTLINE

INTRODUCTORY REVIEW OF NETWORK MODELS

- **collections of the familiar “lumped-parameter” elements: mass, spring, damper, inductor, capacitor, resistor, etc.**

Model representation using block diagrams and bond graphs

EXTENSION TO MULTI-VARIABLE NETWORK COMPONENTS

Model representation using multi-port elements

- **Multi-port elements represent more complex behavior while retaining the clarity and properties of network models**

APPLICATIONS OF MULTI-VARIABLE NETWORK MODELS

Multi-port and nonlinear elements will be applied to

- **different kinds of energy transduction**
  - **electrical to mechanical**
  - **mechanical to fluid**
  - **etc.**
- **thermal processes**
- **nonlinear mechanical systems**
- **convection and matter transport processes**
- **chemical processes**

APPLICATIONS

Examples will emphasize mechanical, electrical and fluid systems and may include

- **electrical machines**
- **fluid power control systems**
- **robotics**
- **power electronics**
- **thermal systems**
- **compressible gas processes**
- **polymeric actuators**
- **etc.**

THEORY

- Some fundamental theoretical aspects of multi-variable network models will be explored
- How physical system structure affects control-relevant behavior
    - zero dynamics
    - relative degree
    - controllability
    - observability
    - etc.