MA621L-Mathematical Modeling

Lecture 1 : Introduction - What? Why? How?

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भारतीय प्रौद्योगिकी संस्थान तिरुपति
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About the Course

Introduction

- A model is not something you read. It is something you **build**
- Listen to Lectures, Read Books, and then Build and Break Models
- If you do not build models yourself, you delude yourself that you understand modelling. You will be awakened only when you face the first open problem in Quiz-1 or Test-1, where nobody tells you which equation to use
- Enough problems are given at the end of each class. Work out those problems before the next class

Introduction

- Work with this course material, think about it, write your own assumptions, question them, solve the model and make yourself comfortable
- If you follow this, a new problem will be familiar to you, like finding your home in a street where you live, as you wandered around your home many times. Otherwise, modelling will be like trying to locate your home from the map locations
- And there is one more difference in this course: for a real problem, **nobody hands you the map**. You draw it. This course is about learning to draw maps

How This Course Is Different

- In your earlier courses, the equation was given and you solved it
- Here the equation is the **answer**, not the question
- A modelling problem has no unique correct answer. It has defensible answers and indefensible ones
- Two students may build two different models of the same reality and both may be right, for different purposes
- **Marking policy:** an unstated assumption costs you more than an arithmetic slip. A clearly reasoned model with a wrong number scores above a correct number with no reasoning

Introduction

- Attend lectures, reread the lecture notes, correct mistakes in them
- Read reference books and textbooks, correlate with lecture notes
- Solve problems from lecture notes, books, past exam papers
- Discuss the subject with your friends and colleagues
- Convincingly explain the topic to your friends so that you will really understand it yourself.

One Model a Week

- Every week, we take **one** real problem and carry it all the way
- Words $\rightarrow$ assumptions $\rightarrow$ equations $\rightarrow$ solution $\rightarrow$ interpretation $\rightarrow$ validation $\rightarrow$ limitations
- 2 hours of theory $+$ 1 hour of workshop, where you build the model and I try to break it
- 14 weeks, 10 models, 42 hours. At the end you will own 10 complete models
- Tools (dimensional analysis, scaling, approximation) are introduced *when the model of that week needs them*, never as a separate syllabus

The Ten Questions

Every model you submit in this course must answer these, in writing.

1. **Why?** What are we looking for?
2. **Find?** What do we want to know?
3. **Given?** What data are known?
4. **Assume?** What can we assume?
5. **How?** How should we look at this model?

The Ten Questions

Every model you submit in this course must answer these, in writing.

6. **Predict?** What will the model predict?
7. **Valid?** Are the predictions valid?
8. **Verified?** Are the predictions right?
9. **Improve?** Can we improve the model?
10. **Use?** How will we use the model?

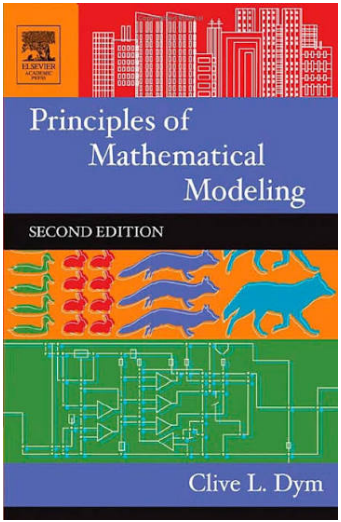
(C. L. Dym, *Principles of Mathematical Modeling*, 2nd Ed., Chapter 1)

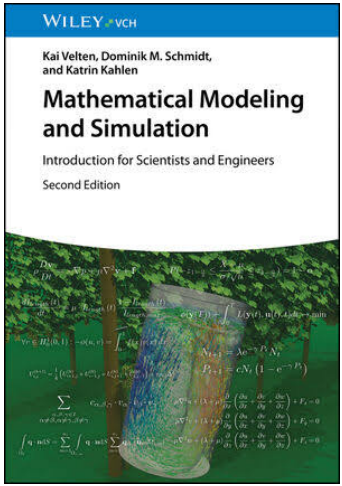
A Warning

- A model that fits your data is not a model that is true
- A model that is true is not a model that is useful
- A computer can solve your equations. It cannot tell you that you wrote down the wrong ones
- So: derive in closed form first, with pencil and paper. Then compute. The closed-form result is your benchmark against which the computer is judged, not the other way round

Text Books

Textbooks


ELSEVIER
ACADEMIC PRESS
Principles of Mathematical Modeling
SECOND EDITION
Clive L. Dym


WILEY-VCH
Kai Velten, Dominik M. Schmidt, and Katrin Kahlen
Mathematical Modeling and Simulation
Introduction for Scientists and Engineers
Second Edition

Marks

Components	Marks
Test - 1	15
Test - 2	15
Model Project	$10 \times 3 = 30$
End Semester	40

Time Table

Lectures are in D-slot; 80% attendance is mandatory.

Day	Time	Lecture/Test
Monday	11:00-11:50	Lecture
Wednesday	10:00-10:50	Lecture
Thursday	9:00-9:30	Lecture
Thursday	9:30-9:50	Class Test: Model Development

Simple Game

Simple Game

Draw a house on a paper

Simple Game

90% of the people have drawn a house like this.

Question

How many of your Houses are like this?

Only 10% people raised their hands

Rapid Fire Round Quiz

Rapid Fire Round Quiz

What does it represent?

$$A = lb$$

100% Area of a Rectangle

Rapid Fire Round Quiz

What does it represent?

$$W = mg$$

90% Weight = Mass $\times$ Gravity

Rapid Fire Round Quiz

What does it represent?

$$F = ma$$

90% Newton's Second Law or Force=Mass $\times$ Acceleration

Rapid Fire Round Quiz

What does it represent?

$$y = mx$$

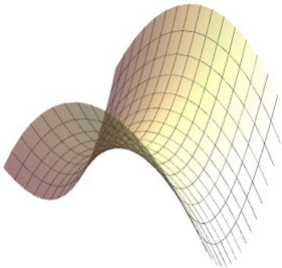
100% Equation of a Straight line passing through the origin

Rapid Fire Round Quiz

What does it represent?

$$z = xy$$

100% Complete Silence



Hyperbolic Paraboloid

Rapid Fire Round Quiz

What does it represent?

$$A = \pi r^2$$

100% Area of a Circle

Rapid Fire Round Quiz

What does it represent?

$$E = mc^2$$

100% Einstein Equation/Theory of Relativity

Rapid Fire Round Quiz

What does it represent?

$$y = ax^2$$

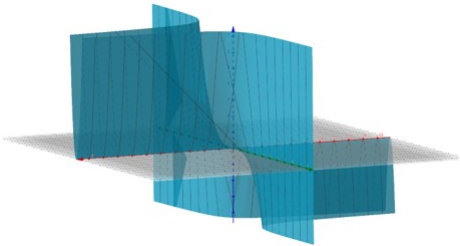
80% Equation of Parabola

Rapid Fire Round Quiz

What does it represent?

$$z = xy^2$$

100% Complete Silence



Rapid Fire Round Quiz

What does it represent?

$$a^2 + b^2 = c^2$$

100% Pythagoras Theorem

Rapid Fire Round Quiz

What does it represent?

$$x^2 + y^2 = r^2$$

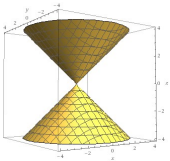
100% Equation of Circle

Rapid Fire Round Quiz

What does it represent?

$$x^2 + y^2 = z^2$$

80% Some 3D Equation



Rapid Fire Round Quiz

What does it represent?

$$\left(x^2+\tfrac{9}{4}y^2+z^2-1\right)^3-x^2z^3-\tfrac{9}{80}y^2z^3=0$$

100% Pin Drop Silence

Rapid Fire Round Quiz

$$\left(x^2+\tfrac{9}{4}y^2+z^2-1\right)^3-x^2z^3-\tfrac{9}{80}y^2z^3=0$$

Rapid Fire Round Quiz

$$y = mx$$

$$A = lb$$

$$F = ma$$

$$W = mg$$

$$z = xy$$

Rapid Fire Round Quiz

$$y = ax^2$$

$$A = \pi r^2$$

$$E = mc^2$$

$$z = xy^2$$

Rapid Fire Round Quiz

$$x^2 + y^2 = r^2 \qquad a^2 + b^2 = c^2$$

$$x^2 + y^2 = z^2$$

Quote

Mathematics is the art of giving the same name to different things

–Henri Poincare

$$f(x, y, z) = 0$$

$y = mx$ $A = lb$ $F = ma$ $W = mg$ $z = xy$

$y = ax^2$ $A = \pi r^2$ $E = mc^2$ $z = xy^2$

$x^2 + y^2 = r^2$ $a^2 + b^2 = c^2$ $x^2 + y^2 = z^2$

$\left(x^2 + \frac{9}{4}y^2 + z^2 - 1\right)^3 - x^2z^3 - \frac{9}{80}y^2z^3 = 0$

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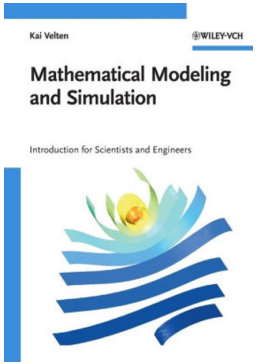
Modelling

Mathematical Model

Kai Velten, Mathematical Modeling and Simulation, Introduction for Scientists and Engineers, *Wiley-VCH Verlag GmbH & Co. KGaA, 2009*



A Few Examples

- Car/Bike is not starting

- Headache

Complexity

- How complex a car is!

- How complex our body/brain is!

Complexity

Remarks

Scientists and Engineers: Break up the complexity of a system and use simplified descriptions of that system

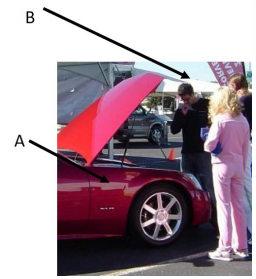
Model

Definition 1 (Model)
To an observer B, an object A^* is a model of an object A to the extent that B can use A^* to answer questions that interest him about A.

Model

Definition (Model)
To an observer B, an object A^* is a model of an object A to the extent that B can use A^* to answer questions that interest him about A.

- B: Driver
- A: Car
- A^*: Fuel Tank/Battery



Best/Simplest Model

Definition 2 (Best Model)
The best model is the simplest model that still serves its purpose, that is, it is still complex enough to help us understand a system and to solve problems.

"*Einstein stated to me that any physical theory, no matter how profound, must be capable of being expressed in such a simple form that even a child could understand it*"
–Louis de Broglie (in his tribute New Perspectives in Physics).

Modelling, Simulation, Validation

Teleological Nature

The word comes from the Greek words telos (meaning end, purpose, or goal) and logos (meaning reason or study). You should ask why this happened.

Aims and Purposes

Main Purpose of Modeling and Simulation: governed by the purpose of problem-solving.

Modeling and Simulation Nature

- Definition
  - Problem Definition to be Solved
  - A question to be answered
  - System Definition for which Answer is Required
- System Analysis
  - Identification of parts of the system related to the question
- Modeling
  - Development of a model of the system based on the results of the systems analysis step

Definition 3 (System)
A system is an object or a collection of objects whose properties we want to study

Modeling and Simulation Nature

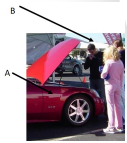
- Simulation
  - Application of the model to the problem
  - Derivation of a strategy to solve the problem
  - Answer the question
- Validation
  - Does the strategy derived in the simulation step solve the problem or answer the question for the real system

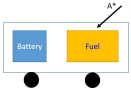
Definition 4 (Simulation)
Simulation is the application of a model with the objective of deriving strategies that help to solve a problem or answer a question pertaining to a system.

Note: Note that the term simulation originates from the Latin word “simulare”, which means “to pretend”: in a simulation, the model pretends to be the real system

Model

- System: Car
- System Analysis: Identifying battery and fuel levels
- Modeling:Check battery and fuel level
- Simulation: Model consists of battery and fuel
- Validation: Apply this concept to real car
- Validated: If refilling the tank or battery, starts the car





Thanks

Doubts and Suggestions

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