Course Welcome & Introduction

Lesson 1

Face-to-Face Vs Zoom

- **This is a face-to-face class.**
- **You are strongly encouraged to come to class to get the full social presences and interactive learning.**

- **Students who are sick or uncomfortable can**
- **Join Zoom Meeting**
- https://erau.zoom.us/j/94433498540
- **Meeting ID: 944 3349 8540**

1: Contact Info

- In-person & on-zoom Office Hours M, W & F: 4–6:00 pm, Office: COAS 301.16.
- On-Zoom Office Hours T & Th https://erau.zoom.us/j/96011124462.
  - Other time available based on appointments:
  - Email, liuho@erau.edu
  - Send message to Cell Phone 386-562-3992,
  - ***Linked Google Page for Signing Appointments*.**
- Course Website

  http://modelsim.wordpress.com

Paperless Homework

- Three Google Drive Links are critical for your success:

1. Student Access – you can view and downloadLecture Notes, Data, Homework and Project Assignments in Shared Google Folder https://drive.google.com/drive/folders/1lRX1snVDMZavqnMdQlnwbCGD2uDFVv9x?usp=sharing

2. Homework Submission Folder

   Have been sent to your ERAU email

3. Team Project Submission Folder

   Will send to you when the team is assigned in the beginning of the 10th week

Introduction of classmates

- Each takes about a minute,
- Name, Major, Career interest, where did you come from, etc.

- 1 minute survey about the Matrix Background
- Hand out the first survey & After School Quiz

In class exercises

1. Go to

http://Modelsim.wordpress.com

Complete the reading material ON TIME

2. Go to the Student Access folder to find your homework assignment and lecture notes.

- Lecture Notes, Data, Homework and Project Assignments in Shared Google Folder

https://drive.google.com/drive/folders/1lRX1snVDMZavqnMdQlnwbCGD2uDFVv9x?usp=sharing

Navigate the course site

http://modelsim.wordpress.com

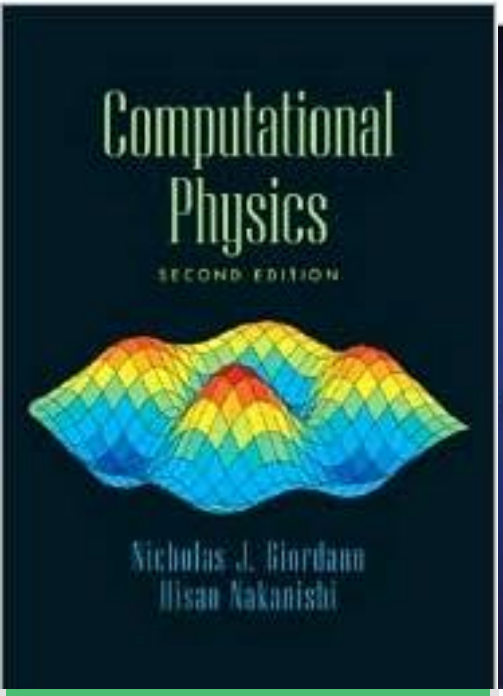
- Get Started,
- Course Calendar
- Module, lecture notes,
- Video
- Homework,

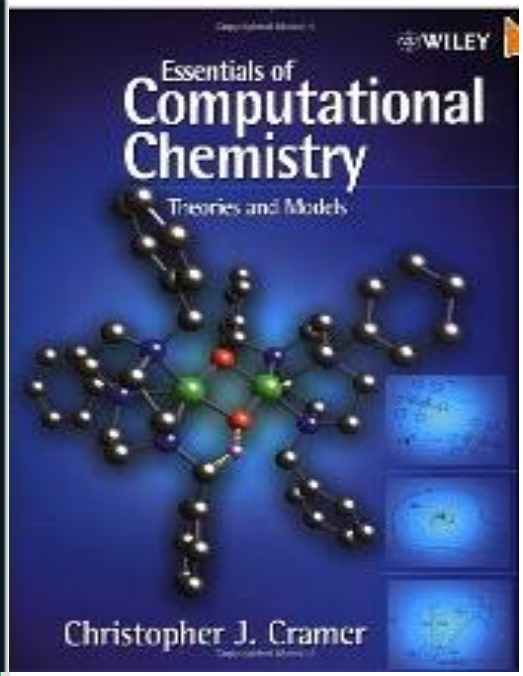
- Communicate, Communicate, Communicate
- Call/email/blogs/message/virtual office

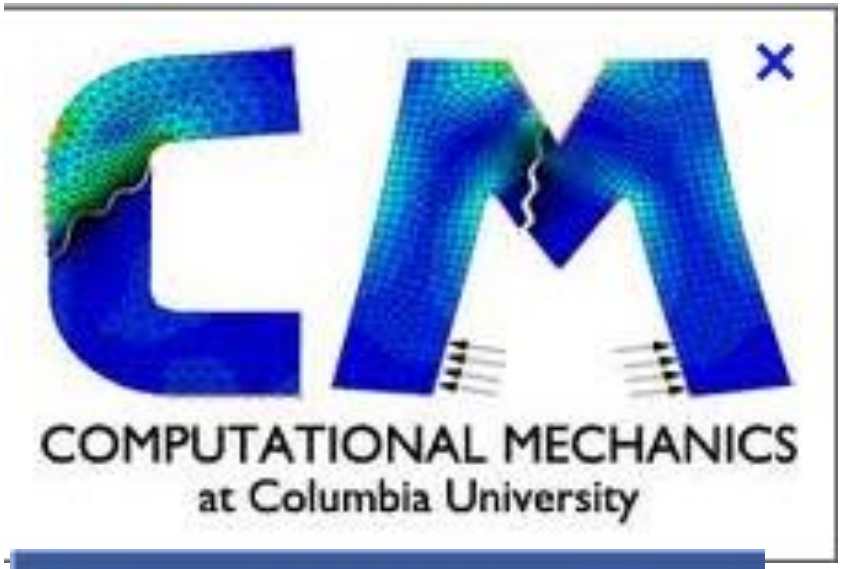
2. Computational Data-enabled Science & Engineering (CDSE)?

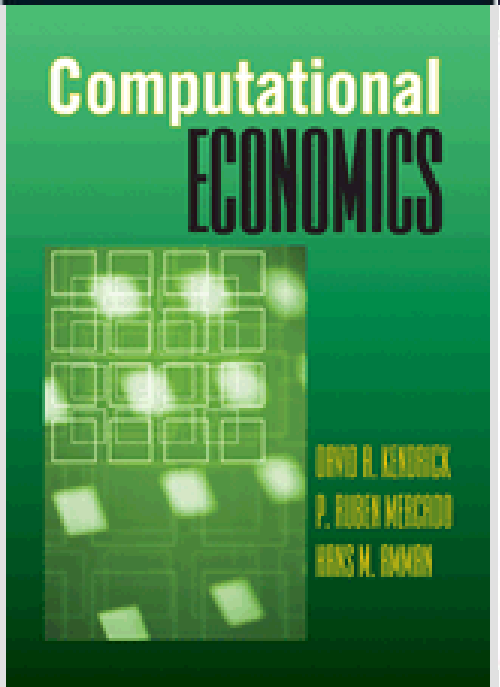
Computational Data-enabled Science & engineering is an emerging field that integrates mathematics,

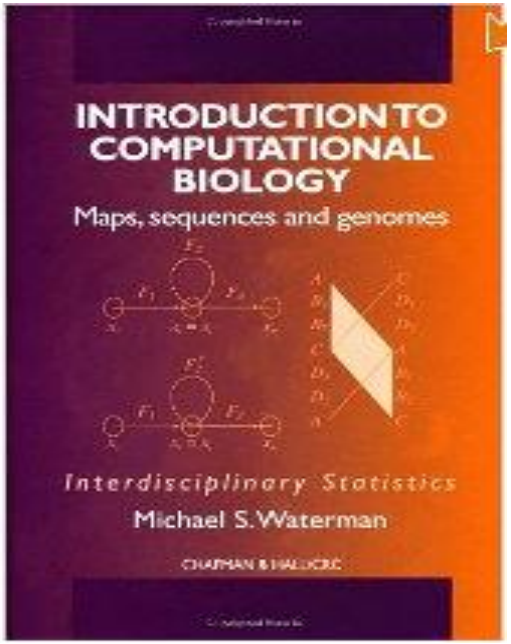
computer science, engineering, and traditional science fields such as biology, chemistry, physics as well as other fields of study such as economics, business and political science.

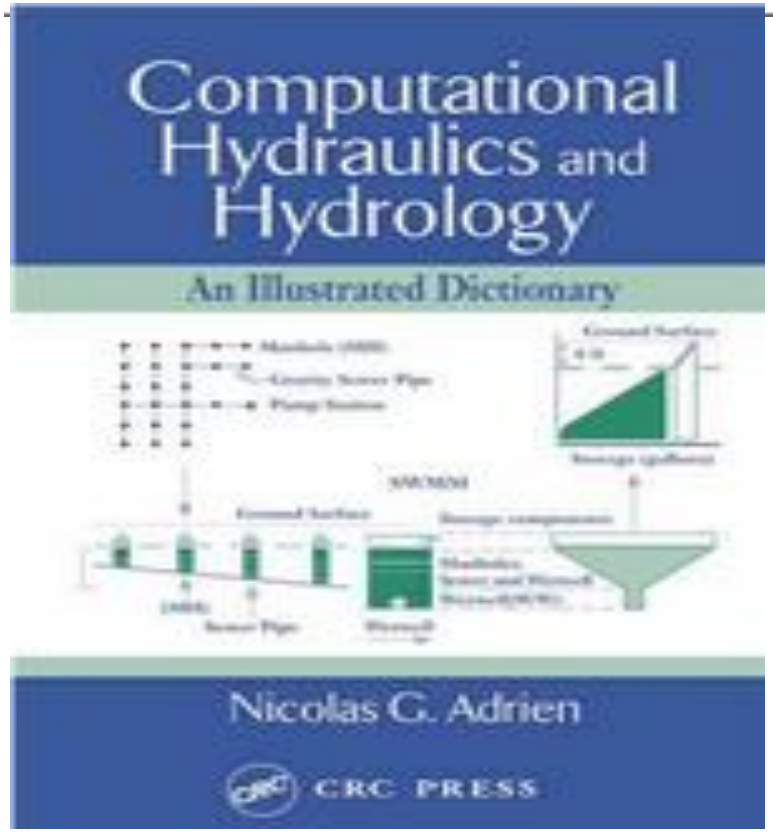

Computational
Physics
SECOND EDITION
Nicholas J. Giordano
Hisao Nakanishi

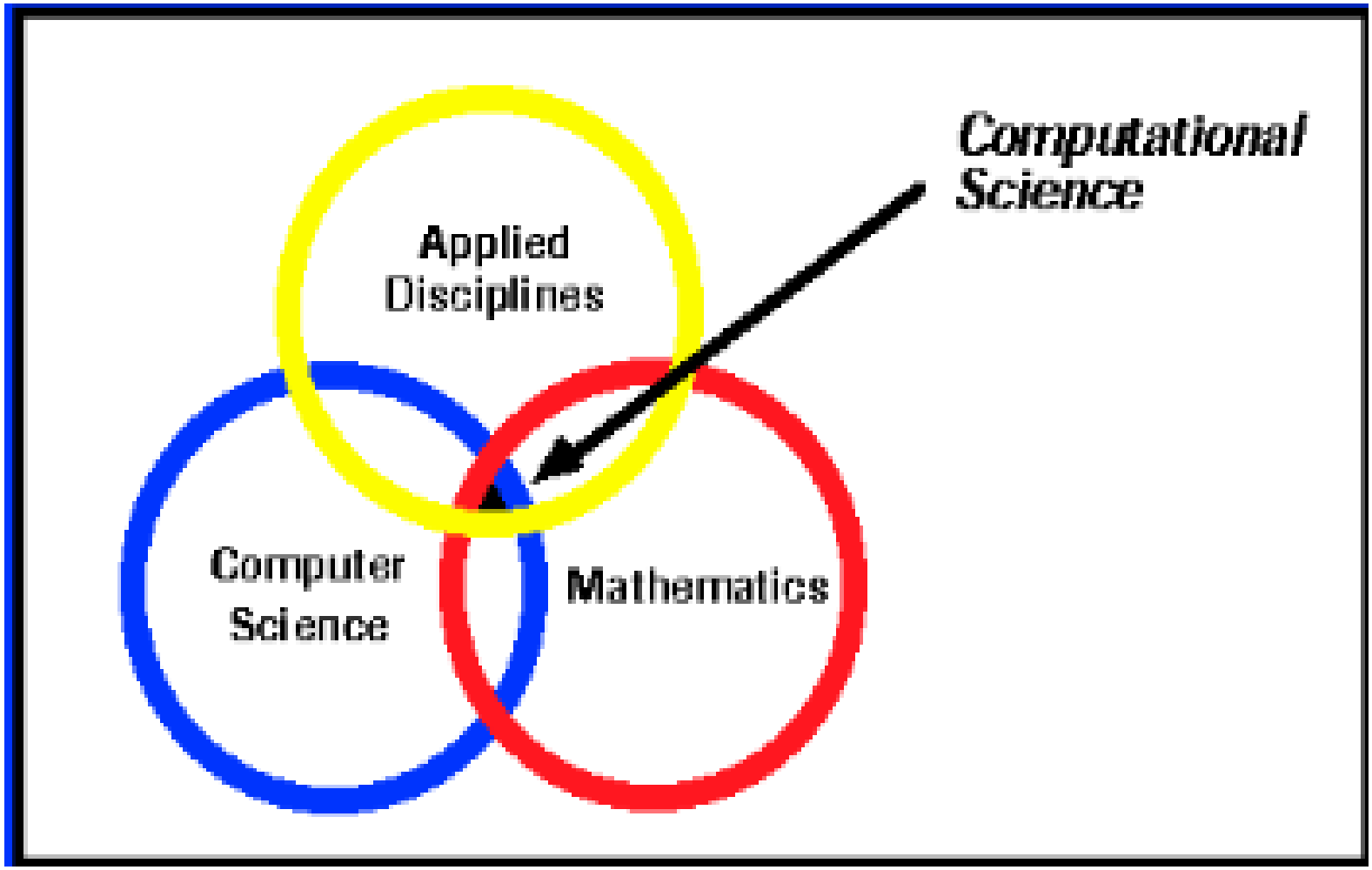

WILEY
Essentials of
Computational
Chemistry
Theories and Models
Christopher J. Cramer


COMPUTATIONAL MECHANICS
at Columbia University

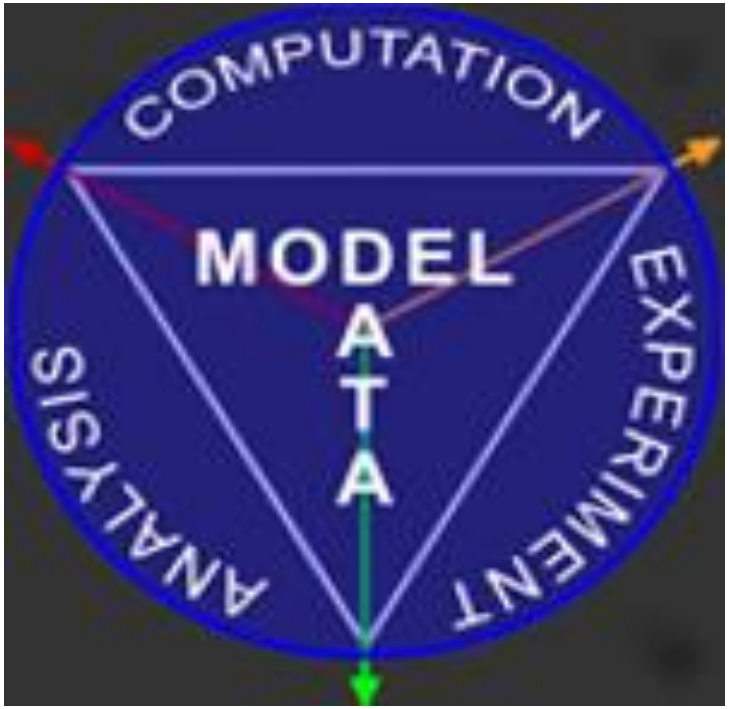

Computational
ECONOMICS
DAVID A. KENDRICK
P. RUBEN MERCADO
HANS M. AMMAN


INTRODUCTION TO
COMPUTATIONAL
BIOLOGY
Maps, sequences and genomes
Interdisciplinary Statistics
Michael S. Waterman
CHAPMAN & HALL/CRC


Computational
Hydraulics and
Hydrology
An Illustrated Dictionary
Nicolas G. Adrien
CRC PRESS


Computational Science
Applied Disciplines
Computer Science
Mathematics

Computation becomes the third leg of Scientific Method besides Theories and Experiments



Ashby 1956

I made it my aim to accept nothing that could not be stated in mathematical form,
for only with this language can one be sure, during one 's progress that one is not unnecessarily changing the meaning of terms, or adding assumptions, or otherwise drifting towards confusion."

3. Logistics

- The course consists of five modules.
- We will spend roughly half time to study the first two modules, focus on the computational language based on ***Matrices*** and some classic model built by scientists and engineers.
- We spend our second half time to learn how to build our own model & simulate models based on the sound scientific principles and system engineering methodology.

Course Calendar

- Module 1 – Matrix Algebra, Applications of Linear Algebra to Population Models GPS coordinate transformations, and Website Ranking by Google.
- Module 2 – Matrix Calculus and Optimization

Test

- Module 3 – Modeling Methodology, System dynamics
- Module 4 - Agent-Based Models
- Module 5 –Stochastic Models: Monte Carlo, Markov Chain.

Individual conceptual modeling and team project

Video Lesson/book Style

- Start with a story of application.
- Then, we look a few questions.
- When we declare variables, parameters, data to describe the application problem, -> Math Model
- Solutions usually answer to the mathematical models.
- Finally you map the discovery from the model to the answers to the original questions.

But, that is not enough

- How do you justify your answer?

  (V&V in Software Engineering)
- How do you convince your stakeholder that your model reflect the real problem? (Validation)
- How do you know your answer is the right answer to the mathematical model? (verification)

4. Role of Math *Modeling*

- Math modeling provides the **methodology and process** to transform an application problem in natural language to math problem.

- Math modeling provides a framework to build models on the base of sound scientific **theory** and reliable **domain knowledge**

- Math modeling provides meaningful test cases (experiments) to

  validate the model &

  verify the solution

What is a Mathematical Model

- *The representation of a scientific problem expressed in mathematical language is called a mathematical model.*
  - e.g. functions, differential equations, or state machines, etc.
  - Mathematics distinguishes from other languages for its preciseness (refutable, not ambiguous), and conciseness.
- *A system should be modeled as simple as possible, but not simpler (Einstein)*
  - Formulate idea precisely, so it is unlikely to let the implicit assumptions slip by or ambiguity misleads readers/users.
  - Concisely for mathematical reducing, deducing

Provide criteria for good/bad models

3C principles

- **Consistency**: *The mathematical model is said to be* ***consistent*** *if the number of unknown dependent variables is equal to the number of independent equations.*
- **Concise:** *A system should be modeled as simple as possible, but not simpler (Einstein)*
- **Clarity**: Formulate idea precisely, so it is unlikely to let the implicit assumptions slip by or ambiguity misleads readers/users.

One Measure of MCM (Mathematical Contesting Modeling) = *The Expressional Capacity /Length of the Expression*

Other benchmark for good models

- A good model makes it easy for the users to trace any artifacts in the model from the upstream entities in the business domain to the downstream artifacts of mathematical variables, etc.

- A good model clearly specifies the model assumptions which based on the first principles in sciences or tradeoff decisions between complexity and accuracy.

- A good model has a cascade of manifestations that are prepared to the different constituents (information hiding)

But, that is not enough

- How do you justify your answer?

  (V&V in Software Engineering)
- How do you convince your stakeholder that your model reflect the real problem? (Validation)
- How do you know your answer is the right answer to the mathematical model? (verification)

2. Classification of Math Models

- **Deterministic vs. probabilistic (stochastic):**

  - A deterministic model is one in which every set of variable states is uniquely determined by parameters in the model and by sets of previous states of these variables. Therefore, deterministic models perform the same way for a given set of initial conditions.

  - A stochastic model evaluates uncertainty: randomness is present, and variable states are not described by unique values, but rather by probability distributions.

5. Classification of Math Models

- **Discrete vs. Continuous:**
  - A discrete model either does not take into account the time or usually uses ticks methods to simulate time advances where all independent variables can be represented as integers.
  - A discrete model typically has finite state in real applications, but it can have infinite but enumerable many states.
  - A continuous model typically take into account the time as a real number over continuous time intervals.
  - A continuous model typically has (uncountable, non-enumerable) states.

Categories of Math Models

- *Continuous Models* -> ODE and PDE
  Temperature Change, Velocity etc.

- *Discrete Models* -> Graphs, Network, State Machines
  Traffic light, Vending Machine States

- *Stochastic Models* -> Probability, Statistics,
  Bank Services, Polling on Politics Opinions

- *Hybrid Models* -> Simulink model on controlling continuous motion based on environmental stimuli.
  Adaptive and Cooperative Cruise Control

Linear or Nonlinear

- Mathematical models are usually composed by variables, and operators that act on these variables, etc.
- If all the operators in a mathematical model exhibit linearity, (proportional relationship) the resulting mathematical model is defined as linear.
- A model is considered to be nonlinear otherwise.

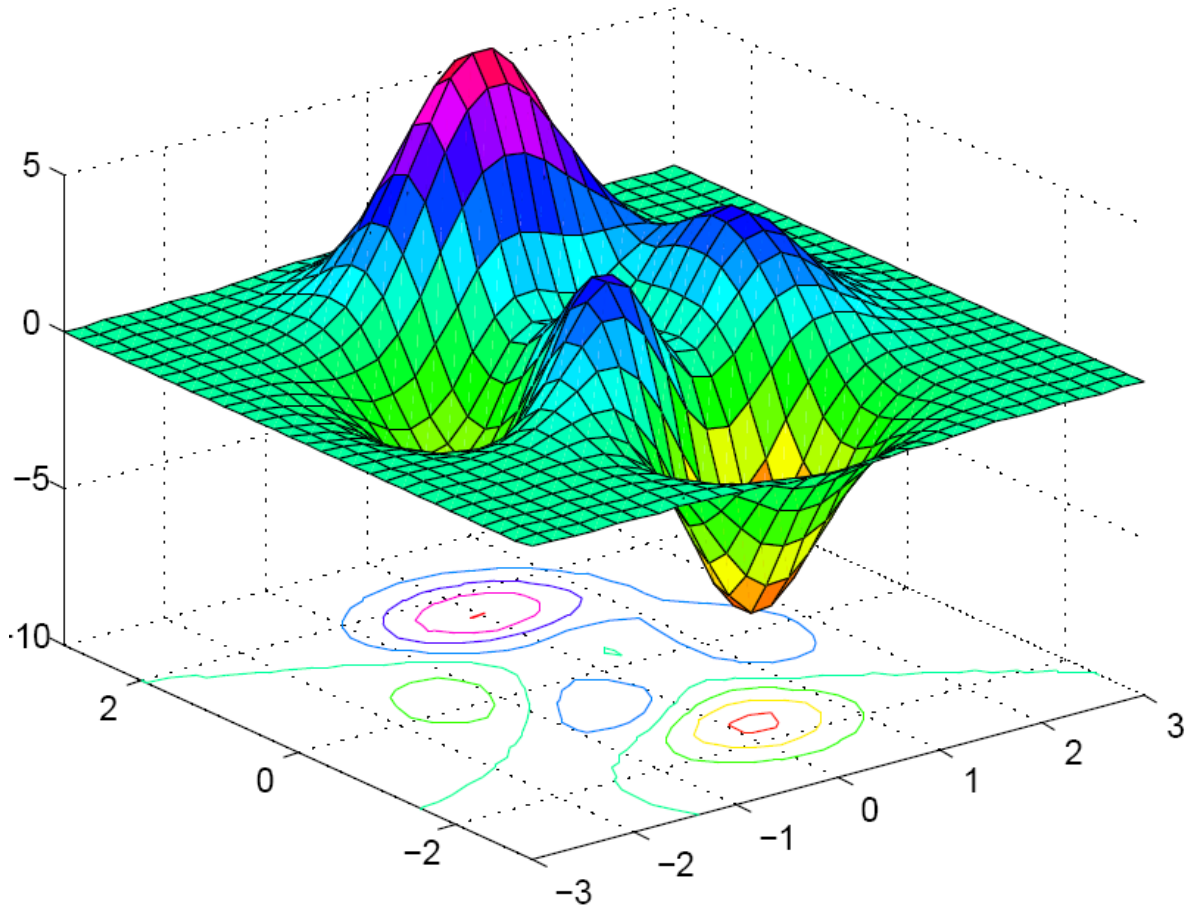
- E.g. If I drive on constant speed 50m/h, the miles that I cover is a linear function of the hours I drive.
- But, the money that you spend on food is not a linear function of your income.

Matrix Operation

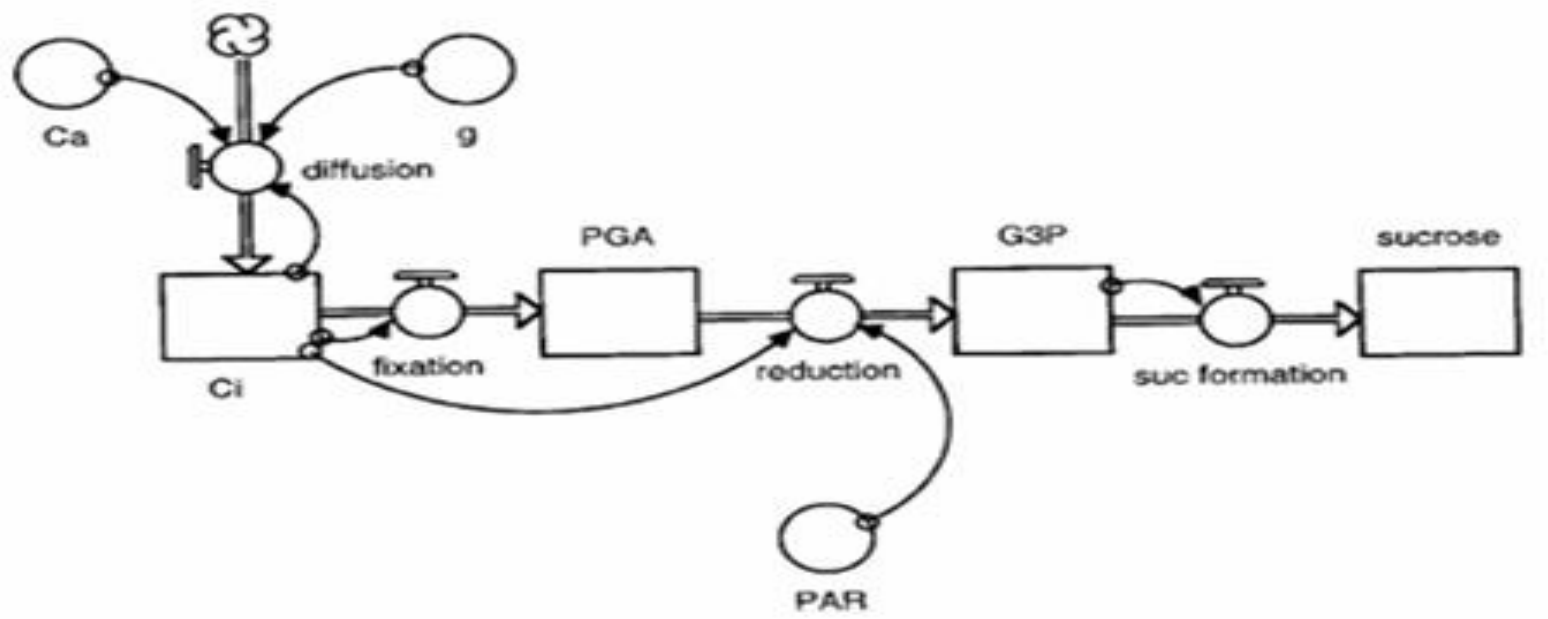
Digit Age: Computational and Data Science
Number, vector, matrix, tensor

Tools:
MS EXCEL Spreadsheet
MATLAB
R
Python: NumPy
Deep Learning Neural Network: TensorFlow

Matrix Calculus & Optimization



Dynamic Model & Stella Simulation



Tools:

Stella from ISEE

Vensim

Agent-based Models

Model and Simulate the

- Agent Characteristics and Behaviors
- Agent Interacts with other agents
- Agent interacts with the environment inputs

Tools

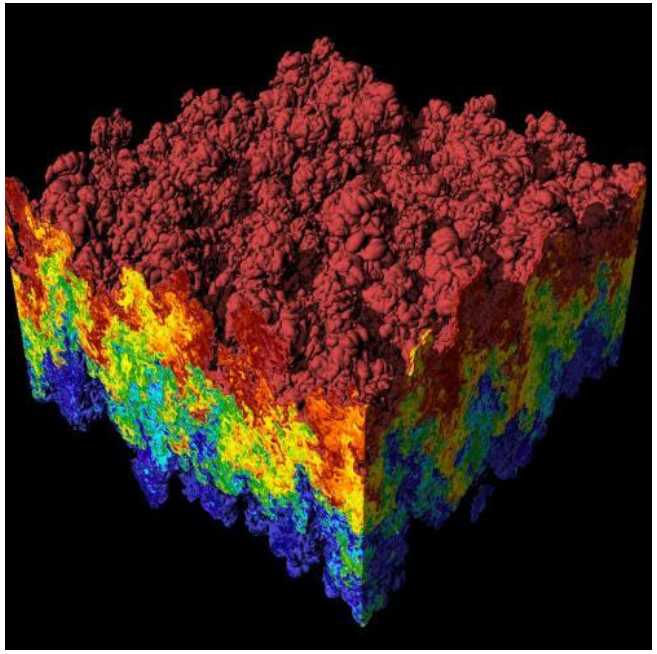
NetLogo

Python Mesa

Agentsheet

Stochastic models: Monte Carlo

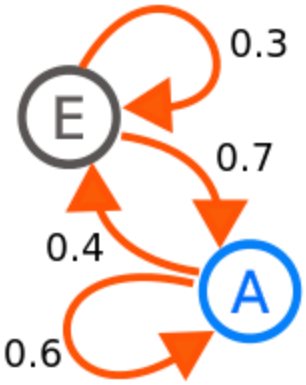
- Monte Carlo methods (or Monte Carlo experiments) are a broad class of computational algorithms t
- They rely on repeated random sampling to obtain numerical results.
- Their essential idea is using randomness to solve problems that might be deterministic in principle.
- They are often used in physical and mathematical problems and are most useful when it is difficult or impossible to use other approaches.
- Monte Carlo methods are mainly used in three distinct problem classes: optimization, numerical integration, and generating draws from a probability distribution.



Monte Carlo Simulation in Computational Physics

Markov Chain

- Markov process is a stochastic or random process,
- It is defined as a collection of random variables.
- Historically, the random variables, (e.g. time), giving the interpretation of a stochastic process representing numerical values of some random system evolving over time,
- The next value of the Markov process depends only on the current value, not the previous values (one step memory)
- A **Markov chain** is a type of Markov process that has a particular type of state space, which dictates the possible values that a stochastic process can take.



Typically, it is a state diagram with one step memory and stochastic transition matrix