## TABLE OF CONTENTS

Note to the reader: This is a customized book for Old Dominion University. However, all available content is listed here in the table of contents, and the content that is not in the book is shown with a strikethrough (e.g. Ghapter 02.00B Physical problem-chemical engineering). If you are an instructor for a numerical methods course and you are interested in adopting this book, we can customize a book for you based on your syllabus. Please contact the first author at autarkaw@yahoo.com or 813-974-5626.
Chapter 01.01 Introduction to numerical methods 1Multiple-choice test 7Problem set 9
Chapter 01.02 Measuring errors 11
True error 11Relative true error 12Approximate error 13Relative approximate error 14
Significant digits 16
Multiple-choice test 18
Problem set 20
Chapter 01.03 Sources of error 22What is round off error? 22
What problems can be created by round off errors? 22
What is truncation error? 2
Can you give me other examples of truncation error? 24
Multiple-choice test 28
Problem set 30
Chapter 01.04 Binary representation of numbers 34Multiple-choice test 41Problem set 43
Chapter 01.05 Floating point representation 44Multiple-choice test 52Problem set 54
Chapter 01.06 Propagation of errors ..... 55
Multiple-choice test 58
Chapter 01.07 Taylor theorem revisited 60
Multiple-choice test 68

## Physical problems

Chapter 02.00A Physical problem - general engineering 70
Chapter 02.00B Physical problem - chemical engineering
Chapter 02.00C Physical problem - civil engineering 72
Ghapter 02.00D Physical problem - computer engineering
Chapter 02.00E Physical problem - electrical engineering
Chapter 02.00F Physical problem -industrial engineering
Chapter 02.00G Physical problem - mechanical engineering 76

## Chapter 02.01 Primer on differential calculus (View it on the web)

Go to http://numericalmethods.eng.usf.edu
$>$ Keyword
> Primer on differential calculus
Multiple-choice test 80
Problem set 82

Chapter 02.02 Differentiation of continuous functions 84
Forward difference approximation of the first derivative 84
Backward difference approximation of the first derivative 87
Forward difference approximation from the Taylor series 89
Finite difference approximation of higher derivatives 92
Multiple-choice test 97
Problem set 99

## Chapter 02.03 Differentiation of discrete functions 101

Forward difference approximation of the first derivative 101
Direct fit polynomials 103
Lagrange polynomial 105
Multiple-choice test 108
Problem set 110

## Physical problems

Chapter 03.00A Physical problem - general engineering 112
Chapter 03.00B Physical problem - chemical engineering
Chapter 03.00C Physical problem - civil engineering 116
Ghapter 0.3.00D Physical problem - computer engineering
Chapter 03.00E Physical problem - electrical engineering
Chapter 03.00F Physical problem industrial engineering
Chapter 03.00G Physical problem - mechanical engineering 122

Chapter 03.01 Solution of quadratic equations 126
Multiple-choice test 129
Problem set 131

## Chapter 03.03 Bisection method of solving a nonlinear equation 133

Bisection method 133
Algorithm for the bisection method 136
Advantages of bisection method 139
Drawbacks of bisection method 140
Multiple-choice test 142
Problem set 144
Chapter 03.04 Newton-Raphson method of solving a nonlinear equation 146
Introduction 146
Derivation 146
Algorithm 147
Drawbacks of the Newton-Raphson method 150
What is an inflection point? 154
Derivation of Newton Raphson method from Taylor series 154
Multiple-choice test 156
Problem set 158

## Chapter 03.05 Secant method of solving nonlinear equations 160

What is the secant method and why would I want to use it instead of the Newton-
Raphson method? 160
Multiple-choice test 165
Problem set 167

Chapter 03.06 False-Position method of solving a nonlinear equation 169
Introduction 169
False-Position method 170
Step-by-step False-Position algorithms 170
Multiple-choice test 175

## Physical problems

Chapter 04.00A Physical problem - general engineering 179
Chapter 04.00B Physical problem - chemical engineering
Chapter 04.00C Physical problem - civil engineering 182
Ghapter 04.00D Physical problem-computer engineering
Chapter 04.00E Physical problem - electrical engineering
Ghapter 04.00F Physical problem industrial engineering
Chapter 04.00G Physical problem - mechanical engineering 187

## Chapter 4.1 Introduction to matrix algebra 193

What does a matrix look like?
What is a matrix? 193
What are the special types of matrices? 194
Square matrix 195
Upper triangular matrix 195
Lower triangular matrix 195
Diagonal matrix 196
Identity matrix 196
Zero matrix 196
Tridiagonal matrices 197
When are two matrices considered to be equal? 197
How do you add two matrices? 198
How do you subtract two matrices? 199
How do I multiply two matrices? 200
What is a scalar product of a constant and a matrix? 202
What is a linear combination of matrices? 203
What are some of the rules of binary matrix operations? 203
Transpose of a matrix 205
Symmetric matrix 206
Matrix algebra is used for solving system of equations. Can you illustrate this concept?
206
Can you divide two matrices? 208
Can I use the concept of the inverse of a matrix to find the solution of a set of equations
[A] [X] = [C]? 209
How do I find the inverse of a matrix? 209
If the inverse of a square matrix [A] exists, is it unique? 212
Multiple-choice test 214
Problem set 216

## Chapter 04.02 Vectors

What is a vector?
When are two vectors equal?
How do you add two vectors?
What is a null vector?
What is a unit vector?
How do you multiply a vector by a sealar?
What do you mean by a linear combination of vectors?
What do you mean by vectors being linearly independent?

What do you mean by the rank of a set of vectors?
Prove that if a set of vectors contains the null vector, the set of vectors is linearly dependent.
Prove that if a set of vectors are linearly independent, then a subset of the $m$ vectors also has to be linearly independent.
Prove that if a set of vectors is linearly dependent, then at least one of the vectors can be written as a linear combination of others.
Prove that if the dimension of a set of vectors is less than the number of vectors in the set, then the set of vectors is linearly dependent
How can vectors be used to write simultaneous linear equations?
What is the definition of the dot product of two vectors?

## Ghapter 04.03 Binary matrix operations

How do you add two matrices?
How do you subtract two matrices?
How do I multiply two matrices?
What is a scalar product of a constant and a matrix?
What is a linear combination of matrices?
What are some of the rules of binary matrix operations?
Commentative law of addition
Associative law of addition
Associative law of multiplication
Distributive law
Is $[A][B]-[B][A]$ ?

## Chapter 04.04 Unary matrix operations

What is the tramspose of a matrix?
What is a symmetric matrix?
What is a skew symmetric matrix?
What is the trace of a matrix?
Define the determinant of a matrix.
Is there a relationship between $\operatorname{det}(\mathrm{AB})$, and $\operatorname{det}(\mathrm{A})$ and $\operatorname{det}(\mathrm{B})$ ?
Are there some other theorems that are important in finding the determinant?

## Chapter 04.05 System of equations

Matrix algebra is used for solving systems of equations. Can you illustrate this concept?
A system of equations can be consistent or inconsistent. What does that mean?
How can one distinguish between a consistent and inconsistent system of equations?
If a solution exists, how do we know whether it is unique?
If we have more equations than unknowns in $[\mathrm{A}][\mathrm{X}]=[\mathrm{C}]$, does it mean the system is incomsistent?
Gan I use the concept of the inverse of a matrix to find the solution of a set of equations
$[\mathrm{A}][\mathrm{X}]=[\mathrm{C}]$ ?
How do I find the inverse of a matrix?
Is there another way to find the inverse of a matrix?
If the inverse of a square matrix [A] exists, is it unique?

## Chapter 04.06 Gaussian elimination 220

How are a set of equations solved numerically? 220
Forward elimination of unknowns 220
Back substitution 222

Are there any pitfalls of Naïve Gauss elimination method? 228
Round-off error 229
What are the techniques for improving Naïve Gauss elimination method? 231
How does Gaussian elimination with partial pivoting differ from Naïve Gauss elimination? 232
Can we use Naïve Gauss elimination methods to find the determinant of a square matrix? 235
What if I cannot find the determinant of the matrix using Naive Gauss elimination method, for example, if I get division by zero problems during Naïve Gauss elimination method? 236
Multiple-choice test 238
Problem set 241

## Chapter 04.07 LU decomposition 243

I hear about LU decomposition used as a method to solve a set of simultaneous linear equations? What is it? 243
How do I decompose a non-singular matrix [A], that is, how do I find $[A]=[L][\mathrm{U}]$ ? 246
How do I find the inverse of a square matrix using LU decomposition? 250
Multiple-choice test 253
Problem set 257

## Chapter 04.08 Gauss-Seidel method 259

Why do we need another method to solve a set of simultaneous linear equations? 259
The above system of equations does not seem to converge. Why? 264
Multiple-choice test 269
Problem set 373

## Ghapter 04.09 Adequacy of solutions

What does it mean by ill conditioned and well conditioned system of equations?
So what if the system of equations is ill conditioning or well conditioning?
To calculate condition number of an invertible square matrix, I need to know what norm of a matrix means. How is the norm of a matrix defined?
How is norm related to the conditioning of the matrix?
What are some of the propenties of norms?
Proof
How do I wse the above theorems to find how many significant digits are correct in my solution vector?

## Chapter 04.10 Eigenvalues and eigenvectors

What does eigenvalue mean?
Gan you give me a physical example application of eigenvalues and eigenvectors?
What is the general definition of eigenvalues and eigenvectors of a square matrix?
How do I find eigenvalues of a square matrix?
What are some of the theorems of eigenvalues and eigenvectors?
How does one find eigenvalues and eigenvectors numerically?
Chapter 04.11 Cholesky and LDL ${ }^{\text {T }}$ Decomposition 274
Symmetrical positive definite (SPD) SLE 274
Re-ordering algorithms for minimizing fill-in terms [1,2] 287

On-line chess-like game for reordering/factorized phase 289
Multiple-choice test 292

## Physical problems

Chapter 05.00A Physical problem - general engineering 300
Ghapter 05.00B Physical problem chemial engineering
Chapter 05.00C Physical problem - civil engineering 302
Chapter 05.00D Physical problem - computer engineering
Ghapter 05.00E Physical problem -electrical engineering
Ghapter 05.00F Physical problem - industrial engineering
Chapter 05.00G Physical problem - mechanical engineering 305
Chapter 05.01 Background of interpolation
Multiple-choice test 309

Chapter 05.02 Direct method of interpolation 311
What is interpolation? 311
Direct method 312
Multiple-choice test 320
Problem set 322

## Chapter 05.03 Newton's divided difference interpolation 324

What is interpolation? 324
Newton's divided difference polynomial method 324
Linear interpolation 325
Quadratic interpolation 327
General form of Newton's divided difference polynomial 330
Multiple-choice test 335
Problem set 337

## Ghapter 05.05-Spline method of interpolation

What is interpolation?
Linear spline interpolation
Quadratic splines
Multiple-choice test
Problemset

Chapter 05.06 Extrapolation is a bad idea
Ghapter 05.07 Higher order interpolation is a bad idea
Chapter 05.08 Why do we need splines?
Chapter 05.10 Shortest path of a robot

## Physical problems

Chapter 06.00A Physical problem - general engineering 339
Chapter 06.00B Physical problem - chemical engineering
Chapter 06.00C Physical problem - civil engineering 343
Ghapter 06.00D Physical problem-computer engineering
Chapter 06.00E Physical problem - electrical engineering
Ghapter 06.00F Physical problem-industrial engineering
Chapter 06.00G Physical problem - mechanical engineering 346
Chapter 06.01 Statistics background of regression analysis 351
Review of statistical terminologies 351
Elementary statistics 351
A brief history of regression 355
Multiple-choice test 359

Chapter 06.02 Introduction of regression analysis 359
What is regression analysis? 359
Comparison of regression and correlation 360
Uses of regression analysis 360
Abuses of regression analysis 360
Extrapolation 361
Least squares methods 363
Why minimize the sum of the square of the residuals? 363
Multiple-choice test
Problem set 365

## Chapter 06.03 Linear regression 366

Why minimize the sum of the square of the residuals? 366
Multiple-choice test 379
Problem set 381

## Chapter 06.04 Nonlinear models for regression 383

Nonlinear models using least squares 383
Exponential model 383
Growth model 387
Polynomial models 389
Linearization of data 393
Exponential model 393
Logarithmic functions 396
Power functions 399
Multiple-choice test 405
Problem set 408

Chapter 06.05 Adequacy of models for regression 411
Quality of fitted model 411
Plot the data and the regression model. 411
Calculate the standard error of estimate. 412
Calculate the coefficient of determination. 414

Find if the model meets the assumptions of random errors. 416
Problem set 422

INTEGRATION
425

## Physical problems

Chapter 07.00A Physical problem - general engineering 425
Ghapter 07.00B Physical problem - chemical engineering
Chapter 07.00C Physical problem - civil engineering 428
Ghapter 07.00D Physical problem - computer engineering
Ghapter 07.00E Physical problem-electrical engineering
Chapter 07.00F Physical problem - industrial engineering
Chapter 07.00G Physical problem - mechanical engineering 534

## Chapter 07.01 Primer on integration (View it on the web)

Go to http://numericalmethods.eng.usf.edu

> >Keyword
> $>$ Primer on integral calculus

Multiple-choice test 438
Problem set 440

## Chapter 07.02 Trapezoidal rule of integration 443

What is integration? 443
What is the trapezoidal rule? 443
Derivation of the trapezoidal rule 444
Multiple-segment trapezoidal rule 450
Error in multiple-segment trapezoidal rule 456
Multiple-choice test 459
Problem set 461

## Chapter 07.03 Simpson's $1 / 3$ rule of integration 464

What is integration? 464
Simpson's 1/3 rule 464
Multiple-segment Simpson's 1/3 rule 471
Error in multiple-segment Simpson's $1 / 3$ rule 474
Multiple-choice test 476
Problem set 478

## Chapter 07.05 Gauss quadrature 480

What is integration? 480
Gauss quadrature rule 481
Derivation of two-point Gaussian quadrature rule 482
Higher point Gaussian quadrature formulas 484
Arguments and weighing factors for n-point Gauss quadrature rules 485
Multiple-choice test 494
Problem set 497

## Ghapter 07.06 Integrating discrete functions

What is integration?
Integrating discrete functions
Trapezoidal rule for discrete functions with unequal segments
xxii

Problem set

## Chapter 07.07 Integrating improper functions

What is integration?
What is an improper integral?
Problem-set

Chapter 07.08 Simpson's 3/8 Rule for integration 499
Introduction 499
Simpson's 3/8 Rule for integration 502
Computer algorithm for mixed Simpson's $1 / 3$ and $3 / 8$ rule for integration 507
Multiple-choice test 509

## Physical problems

Chapter 08.00A Physical problem - general engineering 511
Ghapter 08.00B Physical problem - chemical engineering
Chapter 08.00C Physical problem - civil engineering 515
Ghapter 08.00D Physiad problem- computer engineering
Ghapter 08.00E Physical problem-electrical engineering
Chapter 08.00F Physical problem - industrial engineering
Chapter 08.00G Physical problem - mechanical engineering 517
Chapter 08.01 Primer for ordinary differential equations (View it on web)
Go to http://numericalmethods.eng.usf.edu
$>$ Keyword
> Primer on ordinary differential equations
Multiple-choice test 523
Problem set 525
Chapter 08.02 Euler's method for ordinary differential equations 527
What is Euler's method? 527
Derivation of Euler's method 528
Multiple-choice test 536
Problem set 539

## Chapter 08.03 Runge-Kutta 2nd order method 543

What is the Runge-Kutta 2nd order method? 543
Heun's method 546
Midpoint method 546
Ralston's method 547
How do these three methods compare with results obtained if we found $f^{\prime}(x, y)$
directly? 550
How do we get the 2nd order Runge-Kutta method equations? 551
Multiple-choice test 554
Problem set 557

## Chapter 08.04 Runge-Kutta 4th order method

What is the Rumge Kutta 4th order method?
How does one write a first order differential equation in the above form?
Multiple-choice test
Problem set

Chapter 08.05 On Solving higher order equations 561
Problem set 570
Chapter 08.07 Finite difference method 572
What is the finite difference method? 572
Multiple-choice test 586
Problem set 590

## Physical Problems

Chapter 11.00C Physical problem - civil engineering 593

## Chapter 11.01 Introduction to Fourier series 606

Chapter 11.02 Continuous Fourier series 611
Derivation of formulas for $a_{0}, a_{k}$, and $b_{k} 611$
A FORTRAN program for finding Fourier coefficients $a_{0}, a_{k}$, and $b_{k} 612$
Multiple-choice test 621
Chapter 11.03 Fourier transform pair: frequency and time domain 624
Representation of a complex number in polar coordinates 629
Important notes 630
Non-periodic function 632
Multiple-choice test 635

## Chapter 11.04 Discrete Fourier transform 637

Derivations of DFT Formulas 637
Detailed explanation about aliasing phenomenon, Nyquist samples, Nyquist rate 641
Multiple-choice test 646

## Chapter 11.05 Informal development of Fast Fourier Transform (FFT) 648

Factorized matrix and further operation count 650
Companion node observation 655
Companion node spacing 655
Companion node computation 655
Determination of $W^{P} 656$
Computer implementation to find value of "P" (in $W^{P}$ ) 657
Multiple-choice test 666

## Chapter 11.06 Theoretical Development of FFT 669

FFT algorithms for $N=2^{r} 669$
Consider the case $\mathrm{N}=2^{\mathrm{r}}=2^{3}=8671$
Consider the general case $\mathrm{N}=2^{\mathrm{r}}$ ( $\mathrm{r}=$ any integer number) 673
FFT algorithms for $N=r_{1} r_{2}$ (where $r_{1}, r_{2}$ are integers) 675
General FFT algorithms and relationships between FFT for $\mathrm{N}=2^{(\mathrm{r}=3)}=8$ versus $\mathrm{N}=\mathrm{r}_{1} \mathrm{r}_{2} \mathrm{r}_{3}=(2)(2)(2)=8679$
Twiddle factor FFT algorithms for $\mathrm{N}=\left(\mathrm{r}_{1}=4\right)\left(\mathrm{r}_{2}=4\right)=16681$
Multiple-choice test 684

Index 688

Answers to Selected Problems 694

