Numerical Methods and Programming

DEGREE:	**Degree in Civil Engineering Technology**
COORDINATOR:	**Iván Couceiro**
OTHER LECTURERS:	**José París, Diego Villalba, Andrés Fernández San Miguel**
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WEBPAGE:	**http://caminos.udc.es/info/asignaturas/grado_tecic/311/index.html**

COURSE:	**Third Course, 2024/2025**
TYPE OF SUBJECT:	**Basic Training, 1st Term**
CREDITS:	**4 h/week (6 ECTS)**

Objectives:

To know, understand and apply part of the constructive methods that allow to solve numerically some of the most frequent mathematical problems in Civil Engineering.

Organization:

For 4 hours per week theory classes are taught and problems, previously proposed are solved. Students will solve a series of application problems in the Numerical Analysis Laboratory of the School, for which they must perform several programs in FORTRAN as Course Work. Throughout the course, a number of follow-up test will be proposed to monitor de knowledge acquired.

Classic Bibliography:

- *B. Carnahan, H.A. Luther, J.O. Wilkes, Cálculo Numérico. Métodos. Aplicaciones, Rueda, 1979.*
- *A. Ralston, P. Rabinowitz, A First Course in Numerical Analysis, Mc Graw Hill, 1978.*
- *F.B. Hildebrand, Introduction to numerical analysis, Mc Graw Hill, 1974.*
- *Stoer J. y Burlisch R., Introduction to Numerical Analysis, Springer-Verlag, New York, 1980*
- *Isaacson E. y Keller H.B., Analysis of Numerical Methods, John Wiley & Sons, New York, 1966*
- *W.H. Press, B.P. Flannery, S.A. Teukolsky, W.T. Vetterling, Numerical recipes. The art of scientific computing, Cambridge University Press, 1986.*

Updated Bibliography:

- *M. Pal, Numerical Analysis for Scientists and Engineers, Alpha Science, UK, 2007.*
- *D. Prasad, An Introduction to Numerical Analysis, Alpha Science, 2003.*
- *T. Sauer, Análisis Numérico, Pearson, 2013.*
- *C. Vázquez Espi y J. Burgos, Análisis y Métodos Numéricos, 2011.*
- *G. Wheatley, Análisis Numérico con Aplicaciones, 2001.*
- *J.P. Epperson, An Introduction to Numerical Methods and Analysis, Wiley-blackwell, 2007.*
- *R.B. Bhat y S. Chakraverty, Numerical Analysis in Engineering, Alpha Science, 2003.*
- *S.C. Chapra, R.P. Canale, Métodos Numéricos para Ingenieros, McGraw Hill, 2015.*

System of Evaluation:

In order to pass the course, it is necessary condition to have completed the course work. A final exam is held in January and another one in July. In the evaluation, in addition to the scores obtained in the exams, the grades obtained in the course work (January and July) and in the follow-up tests (January) are taken into account.

Tutorial sessions:

During working hours. Specific times may be published during the exams period.

Additional Information:

It is necessary to have coursed Calculus I, Calculus II, Algebra and Differential Equations.

Program:

1. **FUNDAMENTALS____(6h)**
Introduction. Historical development of Numerical Analysis. Fundamental ideas. Numerical Methods in Civil Engineering. Use and abuse of Numerical Methods. Presentation and interpretation of results. Computer programming.

2. **STORAGE OF NUMBERS IN DIGITAL COMPUTERS________________________(3h)**
Concept of number and number base. Commonly used numbering bases. Change of number base. Bases related by integer powers. Any bases**. Expression of a number in a base.** Integers**.** *Encoding and storage***.** Real numbers**.** *Fixed and floating point representation. Encoding and storage. Rounding. Precision. Operations with limited precision.*

3. **ALGORITHMS____(3h)**
Concept. Classification and properties. Direct or finite algorithms. Computing time. Classification**. Iterative algorithms.** Convergence order. Linear convergence. Convergence speed. Super-linear convergence. Practical convergence criteria Truncation**. Operations with polynomials.** Horner's rule. Synthetic division.

4. **ERROR ANALYSIS____(6h)**
Concept and classification. Absolute and relative error. Errors inherent to the data. Rounding error. Truncation error. Total error. **Error propagation.** Elementary arithmetic operations. Evaluation of functions. Statistical error estimation and error bound. **Numerical instability. Elementary error reduction and control techniques.**

5. **MATRICES STORAGE AND HANDLING___________________________________(4h)**
Full matrices. Full symmetric matrices. Banded Matrices. Banded symmetric matrices. Sky-line or column profile matrices. Sparse matrices.

6. **DIRECT METHODS FOR LINEAR SYSTEMS OF EQUATIONS______________(12h)**
Introduction. Standards. Spectral radius. Condition number. Ill-conditioned matrices. Matrix inversion and determinant calculation. Manipulation of symmetric, banded, profile and unstructured matrices. Treatment of multiple vectors of independent terms**. Systems with immediate solution.** Diagonal matrix. Upper triangular matrix Lower triangular matrix**. Elimination methods. Gaussian elimination. Gauss-Jordan elimination. Decomposition methods.** LU or LDU Crout's decomposition. $L\,L^T$ or $LD\,L^T$ Cholesky's decomposition. Tridiagonal systems. **Other direct methods. Summary and recommendations**.

7. **ITERATIVE AND SEMI-ITERATIVE METHODS FOR LINEAR SYSTEMS OF EQUATIONS____(8h)**
Introduction. Motivation. Iterative refinement of the solution obtained by direct methods. Relationship between the solution of linear systems and the computation of extrema of quadratic functions**. Iterative methods.** General approach. Convergence conditions. Methods with proper name**.** *Gradient method. Jacobi's method. Gauss-Seidel method. Over relaxation. Preconditioning***. Semi-iterative methods.** Conjugate Direction Methods. Conjugate Gradients Method**. Summary and recommendations.**

8. **NON-LINEAR EQUATIONS____(12h)**
Introduction. Bisection method. Calculation of roots of functions. Functional Iteration Methods. *Convergence conditions in an interval: contractive functions; Lipschitz conditions. Asymptotic convergence conditions. Propagation of rounding errors***.** Fixed Point Iteration Methods. *Formulation. Asymptotic convergence factor. Convergence improvement***.** Newton's method and derivatives. *Newton's method. Newton's method for multiple roots. Whittaker's method. Secant method. Regula-falsi method. Müller's method. Higher order methods.* Convergence acceleration**.** *Aitken acceleration. Aitken's theorem. Steffensen's method***.** Summary and recommendations**. Solution of systems of nonlinear equations.** Functional Iteration Methods**.** *Asymptotic convergence conditions. Methods of Fixed Point Iterations.* Newton's methods and derivatives**.** *Newton-Raphson method. Simplified Newton. Whittaker's method. Secant methods ("Quasi-Newton")***.** Summary and recommendations.

9. **BASIC TECHNIQUES FOR NUMERICAL INTEGRATION____________________(6h)**
Motivation. Calculation of definite integrals. Composite quadratures: trapezoidal and Simpson's formulas. Treatment of functions with discontinuity points and singularities**. Solving Ordinary Differential Equations.** General concepts. Euler's method. Methods based on Taylor series. Runge-Kutta methods**.** *General approach. Most common methods***.** Summary and recommendations.