Course Code: **EML305**
Course Title: **Computational Physics of Fluids**
Instructors: **Santosh Ansumali**
Credits: **4.0**

1. **Introduction to Computing (3 Hours)**
   I. Number system and computers
   II. Basics of Computer Architecture
2. **Introduction to distributed Computing (3 Hours)**
   I. Introduction to distributed computing
   II. Amdahl's law and Gustafson's law
   III. MPI parallelization and SIMD vectorization
3. **Introduction to High Performance Computing (2 Hours)**
   I. Memory bound vs compute bound codes
   II. Memory Bandwidth optimizations and Roofline Model
4. **Backward Error Analysis (3 Hours)**
   I. Representation and Computation Error
   II. Error Accumulation and Catastrophic Cancellation
   III. Forward and Backward Error Analysis
   IV. Backward error analysis in linear Algebra
   V. Effective equations for difference equations
   VI. Modified Equation approach for finite difference
5. **Orthogonal Polynomial (3 hours)**
   I. Functions as vector
   II. Hermite Polynomials
   III. Legendre Polynomials
   IV. Chebyshev Polynomials and Minimax property
   V. Guassian Quadrature
   VI. Approximation by orthogonal polynomials

6. **Ordinary Differential Equations (4 Hours)**
   I. One-step methods
   II. Runga Kutta and Multi-step methods
   III. Symplectic Integrators
   IV. Stiff Equations and Projective Euler
7. **Particle Based Methods – (8 Hours)**
   I. Molecular Dynamics, Hard Sphere Dynamics,
   II. Discrete simulation Monte Carlo
   III. Multi-Particle Collision Dynamics,
   IV. Brownian Dynamics Method

8. **Finite Difference Method (4 hours)**
   I. Introduction to Finite difference with Advection-Diffusion equations
   II. Von Neumann Analysis
   III. Discrete Differential Operators
   IV. Artificial viscosity Methods
   V. Lax-Wandroff Method
   VI. Crank-Nicholson Method
   VII. Mac-Cormack Method for Advection equation
   VIII. Fractional Step Methods

9. **Introduction to Computational Fluid Dynamics (4 hours)**

I. Pseudo-compressibility Method
II. Pressure Projection Method
III. Pseudo-Spectral Method

10. **Introduction to Kinetic Theory of Gases (6 Hours)**
    I. Distribution function, Mean Free path, Maxwell-Boltzmann Distribution,
    II. Transport Properties Estimates
    III. Boltzmann Equation
    IV. Models of Boltzmann Equation: BGK, Fokker-Planck, ES-BGK
11. **Maxwell-Boltzmann distribution: A deep dive (4 Hours)**
    I. Maxwell derivation of Equilibrium Distribution
    II. Boltzmann's Variational World
    III. Discrete Variational Problem
    IV. Exact solutions and perturbation methods
    V. Guass-Hermite expansion
    VI. Quasi-Equilibrium distribution
12. **Methods of Reduced Description (4 Hours)**
    I. Moment Chain
    II. Hydrodynamic Limit
    III. Hilbert Expansion
    IV. Chapman-Enskog Method
    V. Grad's Moment Method
    VI. Maximum Entropy's Method
    VII. Hybrid approaches such as R13 method
13. **Introduction to Lattice Boltzmann Models (4 Hours)**
    I. Discrete Velocity Models for Hydrodynamics,
    II. Basic 2D and 3D implementations, Boundary Conditions,
    III. Entropic Lattice Boltzmann
    IV. Multiphase Flow
    V. LBM as PDE solver

Submission method

- All HWs need to be submitted electronically by emailing to the instructor by the designated time.
- Please submit your homework in the LaTex and pdf format.
- You need to create a gitlab page and put your homework codes/documents there and share with course githab account.
- The solutions and calculations must be clearly stated. Use of pictorial sketches and graphs, where required, are strongly preferred.