# Introduction to Computational Fluid Dynamics using OpenFOAM and Octave

Lakshman Anumolu
Kumaresh Selvakumar
(August 28, 2023)

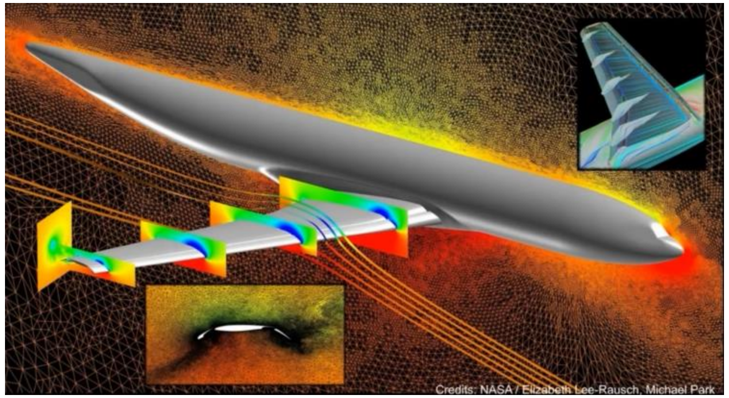
# Overview

- Brief introduction
- Continuum Approximation & Governing Equations
- Installation

# About this Course

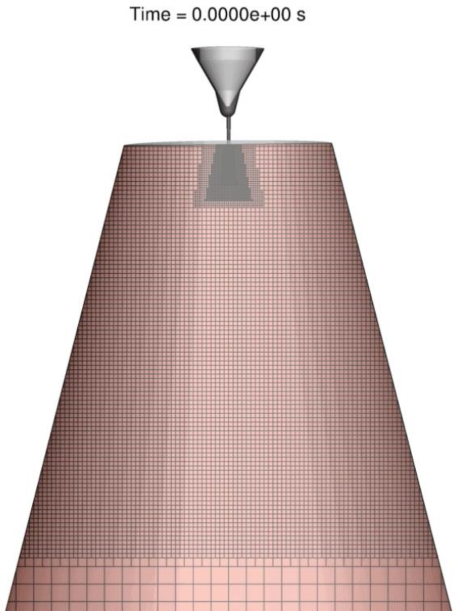
- Instructor: Lakshman Anumolu
- TA: Kumaresh Selvakumar
- Course duration per session: 45-55 mins
- Requirements:
  - Virtual box and installing OS & softwares.
  - Interest to learn CFD using OpenFOAM & Octave
  - **Interest to ask questions**
  - **Work as a team**
- Exercises: 20% (equal weightage)
- Projects: 10%, 10%, 20%, 40%
  - Final project presentations & aim to use those at conferences

# Computational Fluid Dynamics




Credit: NASA

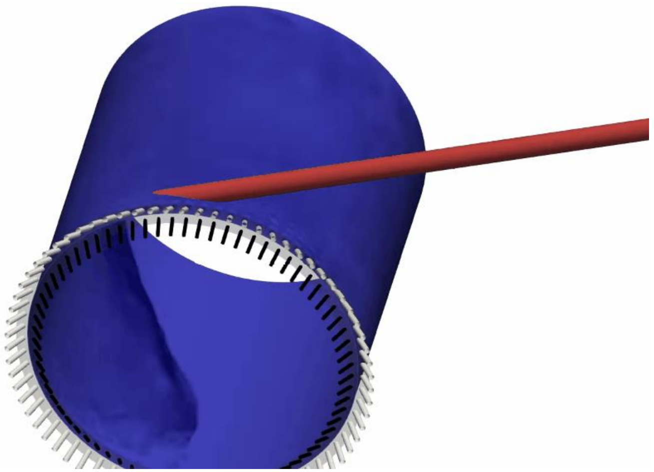
Anumolu (2019)




Anumolu, et al. (2022)

## Why CFD?

- Speed of performing tests for different scenarios
- Cost
- Parametric study



Credit: CSI

# Computational Fluid Dynamics (CFD)

References:

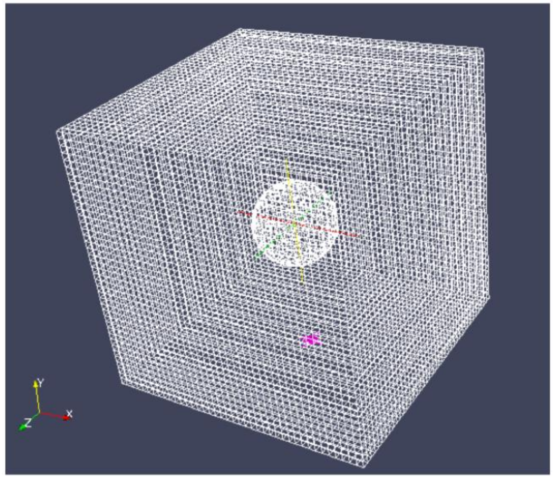
- Ferziger and Peric; Computational Methods for Fluid Dynamics.
- S. Patankar; Numerical Heat Transfer and Fluid Flow.
- Tannehill et al.; Computational Fluid Mechanics and Heat Transfer.
- Versteeg, Malalasekera; An Introduction to Computational Fluid Dynamics.

- C.J. Greenshields, H.G. Weller; Notes on CFD: General Principles.

*References used for this course:*

- *Diversified & interdisciplinary.*

# CFD - Workflow



Generate mesh

OpenFOAM simulation

Perform simulation

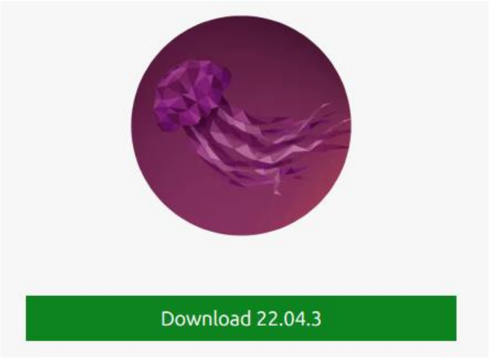
Post-process results

# Tools for this Course

**Exercise-1**

**Install required tools**

- Operating System:
  - Ubuntu 22.04




- Softwares:
  - OpenFOAM v2306

OpenFOAM®

OpenFOAM-v2306

openfoam

  - Octave

GNU Octave

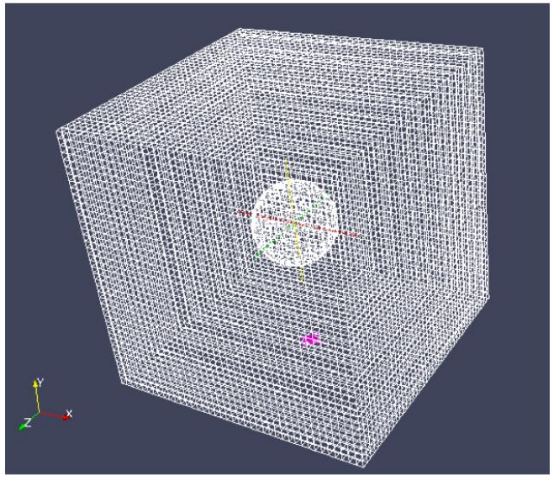
# Things TODO by YOU

**Exercise-1**

**Create required accounts**

- Create a github account:
  - https://github.com
  - Discussion forum:
    - https://github.com/exaslate-courses/cfd-openfoam-b1/discussions
- Part of WhatsApp group
  - https://chat.whatsapp.com/F6Xax0pIxOsJ9MgtCgTXzD
- Queries
  - 30 mins Sunday 8AM-8:30AM IST
  - Ask in github discussion forums
  - WhatsApp for quick queries and use as a reference tool

# CFD – Workflow [as an application engineer]



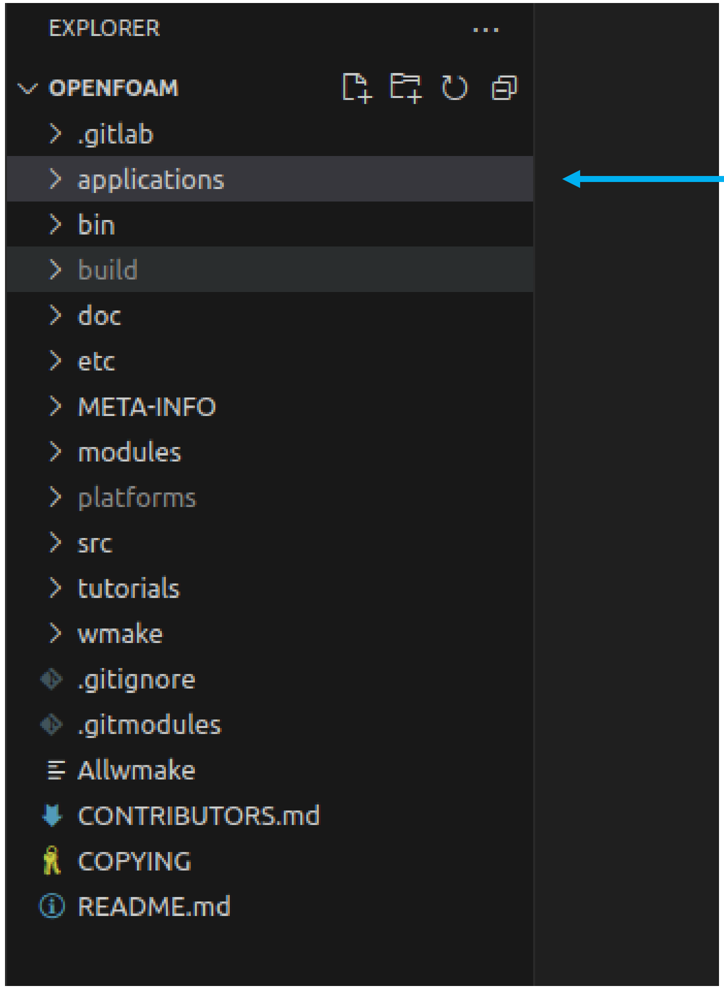
OpenFOAM simulation

Generate mesh

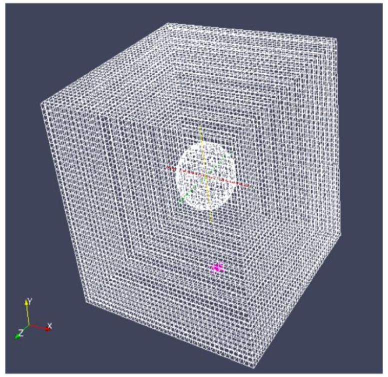
Perform simulation

Post-process results

# CFD – Workflow [as a developer]



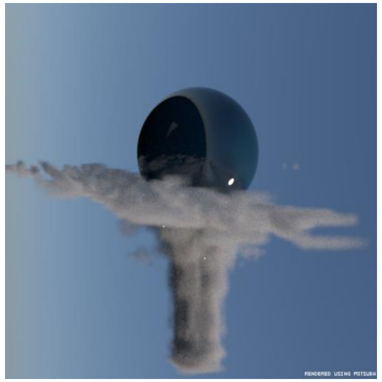

Solvers



Generate mesh

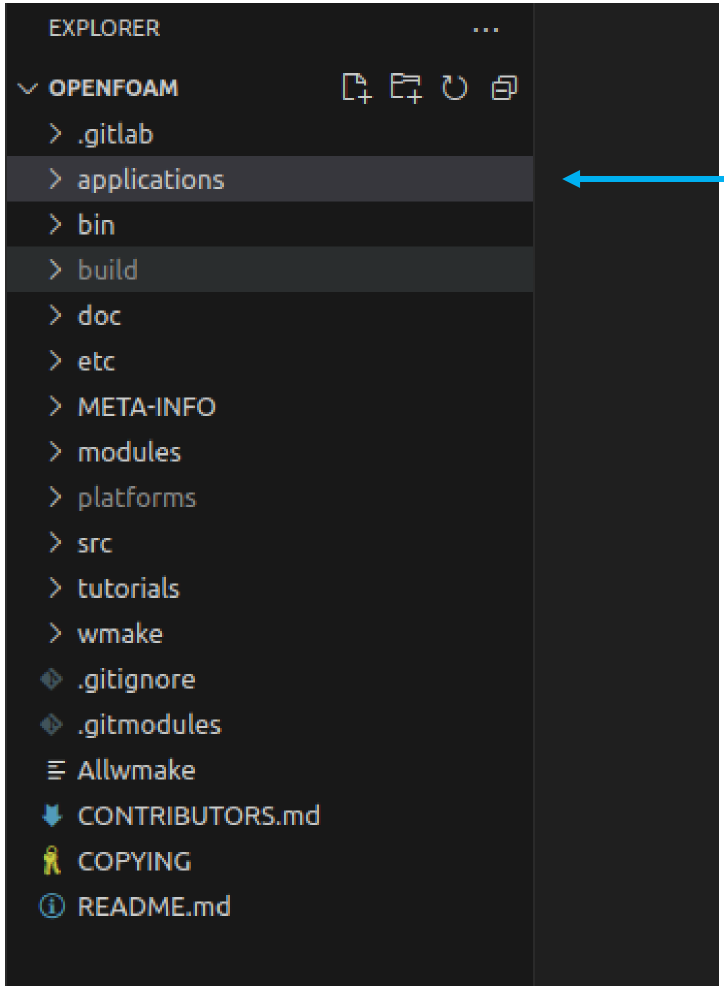
OpenFOAM simulation

Perform simulation

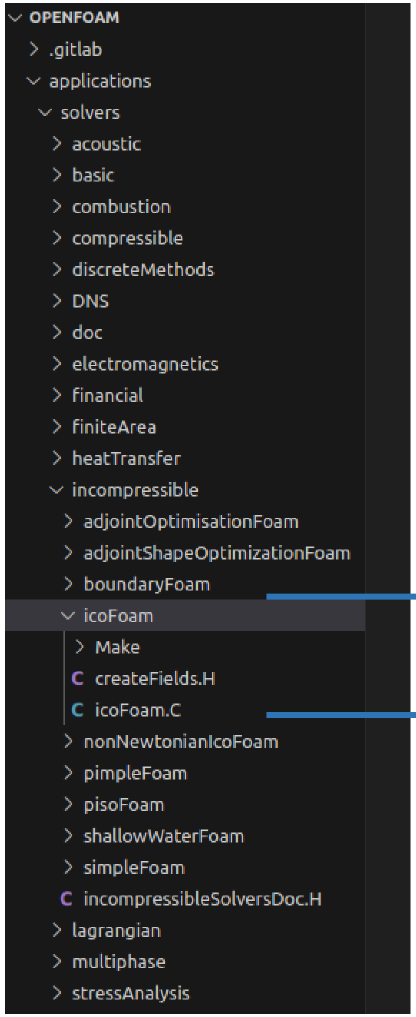


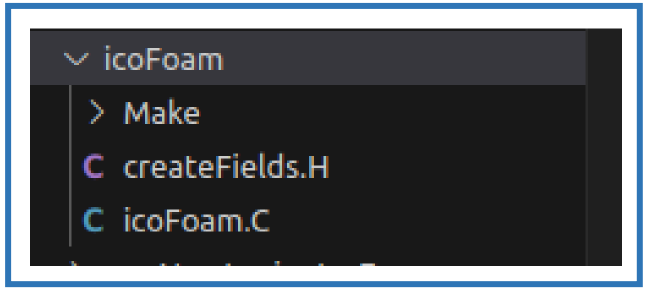
Post-process results

# CFD – Workflow [as a developer]




Solvers




**Transient,
incompressible solver.**

# Takeaway Points

- OS and tools to install
  - Ubuntu, OpenFOAM, Octave
- Create github accounts and use github discussions as forums

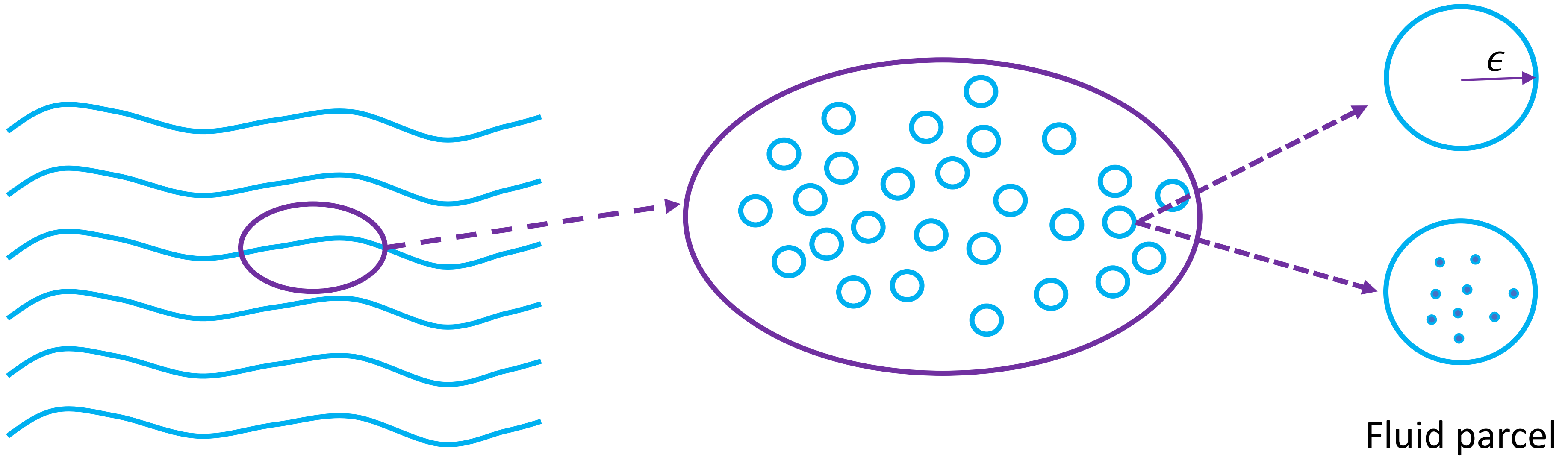
- Steps as a CFD engineer
- OpenFOAM code structure

# CFD Fundamentals
# &
# Governing Equations

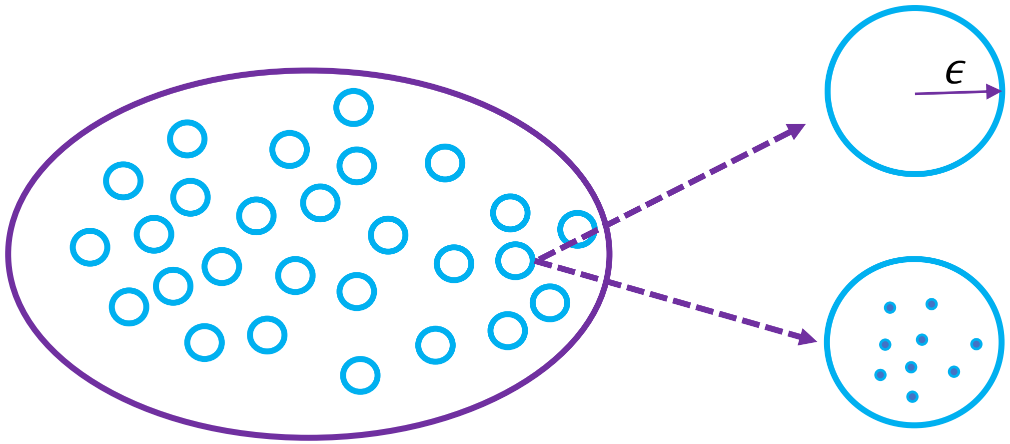
# Fluid

- A substance whose molecular structure offers no resistance to external forces

  - Ferziger, Peric

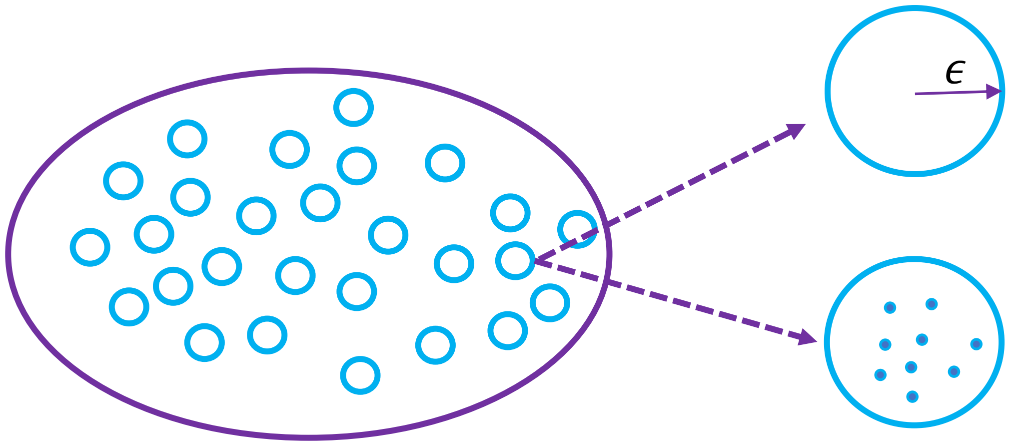


# Fluid (Continuum)

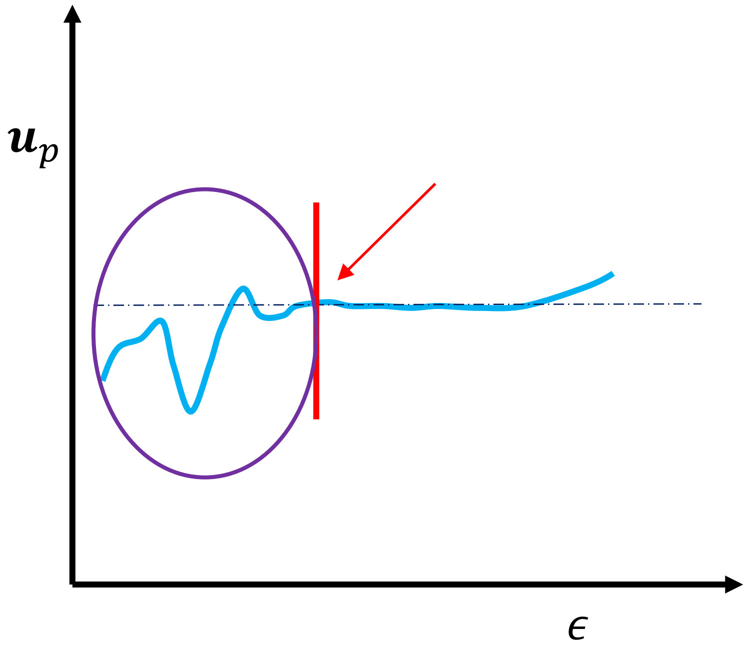



$$\boldsymbol{u}_p = \frac{\sum_{i=1}^{N_{mol}} \boldsymbol{u}_{mol}}{N_{mol}}$$

# Fluid (Continuum)




Continuum approximation




Fluid velocity: $\boldsymbol{u}(\boldsymbol{x}, t)$

# Governing Equations

- Conservation of mass

$$\frac{\partial \rho}{\partial t} + \frac{\partial \rho u}{\partial x} = 0 \qquad 3D\colon \frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \boldsymbol{u}) = 0$$

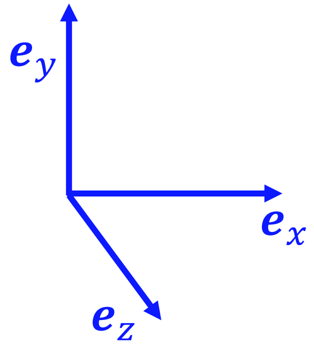
- Conservation of momentum

$$\frac{\partial \rho \boldsymbol{u}}{\partial t} + \nabla \cdot (\rho \boldsymbol{u}\boldsymbol{u}) = -\nabla p + \nabla \cdot \boldsymbol{\sigma} + F_b$$

# Mathematical Operations

- Gradient

$$\nabla \rho = \left(\frac{\partial}{\partial x}\boldsymbol{e}_x + \frac{\partial}{\partial y}\boldsymbol{e}_y + \frac{\partial}{\partial z}\boldsymbol{e}_z\right)\rho = \left(\frac{\partial \rho}{\partial x}\boldsymbol{e}_x + \frac{\partial \rho}{\partial y}\boldsymbol{e}_y + \frac{\partial \rho}{\partial z}\boldsymbol{e}_z\right)$$




$$\nabla \boldsymbol{u} = \begin{bmatrix} \partial u/\partial x & \partial v/\partial x & \partial w/\partial x \\ \partial u/\partial y & \partial v/\partial y & \partial w/\partial y \\ \partial u/\partial z & \partial v/\partial z & \partial w/\partial z \end{bmatrix}$$

- Divergence

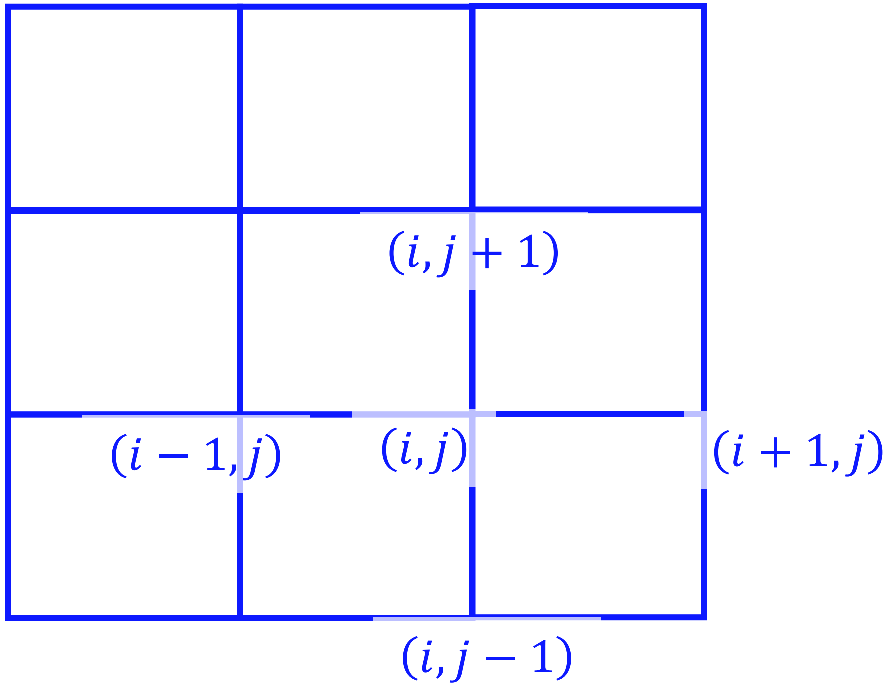
$$\nabla \cdot \boldsymbol{u} = \left(\frac{\partial}{\partial x}\boldsymbol{e}_x + \frac{\partial}{\partial y}\boldsymbol{e}_y + \frac{\partial}{\partial z}\boldsymbol{e}_z\right)\left(u\boldsymbol{e}_x + v\boldsymbol{e}_y + w\boldsymbol{e}_z\right) = \left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z}\right)$$

# Discrete Operations

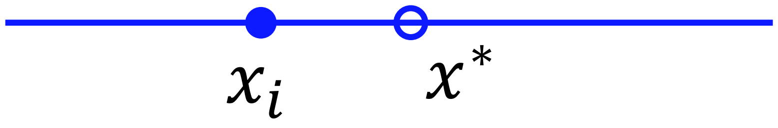
- Finite difference

$$\nabla\rho = \left(\frac{\partial}{\partial x}\boldsymbol{e}_x + \frac{\partial}{\partial y}\boldsymbol{e}_y + \frac{\partial}{\partial z}\boldsymbol{e}_z\right)\rho = \left(\frac{\partial\rho}{\partial x}\boldsymbol{e}_x + \frac{\partial\rho}{\partial y}\boldsymbol{e}_y + \frac{\partial\rho}{\partial z}\boldsymbol{e}_z\right)$$

$$\left(\frac{\partial\rho}{\partial x}\right)_{i,j} = \frac{\rho_{i+1,j} - \rho_{i-1,j}}{2\Delta x}$$



# Taylor Series: Discrete Operations




$$\rho(x^*) = \rho(x_i) + (x^* - x_i)\left(\frac{\partial \rho}{\partial x}\right)_i + (x^* - x_i)^2\left(\frac{\partial^2 \rho}{\partial x^2}\right)_i + (x^* - x_i)^3\left(\frac{\partial^3 \rho}{\partial x^3}\right)_i + \cdots$$

# Taylor Series: Discrete Operations


$$\rho(x_{i+1}) = \rho(x_i) + (x_{i+1} - x_i)\left(\frac{\partial \rho}{\partial x}\right)_i + (x_{i+1} - x_i)^2\left(\frac{\partial^2 \rho}{\partial x^2}\right)_i + (x_{i+1} - x_i)^3\left(\frac{\partial^3 \rho}{\partial x^3}\right)_i + \cdots$$

$$\rho(x_{i+1}) = \rho(x_i) + (x_{i+1} - x_i)\left(\frac{\partial \rho}{\partial x}\right)_i + O\left(\Delta x_i^2\right); \qquad \Delta x_i = (x_{i+1} - x_i)$$

$$\rho(x_{i+1}) = \rho(x_i) + \Delta x_i\left(\frac{\partial \rho}{\partial x}\right)_i + O\left(\Delta x_i^2\right)$$

# Taylor Series: Discrete Operations

$$\rho(x_{i+1}) = \rho(x_i) + \Delta x_i \left(\frac{\partial \rho}{\partial x}\right)_i + O(\Delta x_i^2)$$

$$\left(\frac{\partial \rho}{\partial x}\right)_i = \frac{\rho(x_{i+1}) - \rho(x_i)}{\Delta x_i} + \frac{1}{\Delta x_i} O(\Delta x_i^2)$$

$$\left(\frac{\partial \rho}{\partial x}\right)_i = \frac{\rho(x_{i+1}) - \rho(x_i)}{\Delta x_i} + O(\Delta x_i)$$

$$\left(\frac{\partial \rho}{\partial x}\right)_i \approx \frac{\rho(x_{i+1}) - \rho(x_i)}{\Delta x_i}$$

- Finite difference

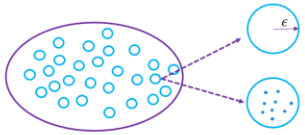
$$\nabla \rho = \left(\frac{\partial}{\partial x}\boldsymbol{e}_x + \frac{\partial}{\partial y}\boldsymbol{e}_y + \frac{\partial}{\partial z}\boldsymbol{e}_z\right)\rho = \left(\frac{\partial \rho}{\partial x}\boldsymbol{e}_x + \frac{\partial \rho}{\partial y}\boldsymbol{e}_y + \frac{\partial \rho}{\partial z}\boldsymbol{e}_z\right)$$

$$\left(\frac{\partial \rho}{\partial x}\right)_{i,j} = \frac{\rho_{i+1,j} - \rho_{i-1,j}}{2\Delta x}$$

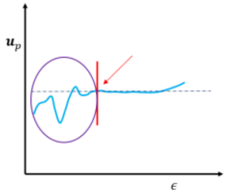
# What Did We Discuss?

- Continuum approximation

Fluid (Continuum)



Continuum approximation




Fluid velocity: $\boldsymbol{u}(\boldsymbol{x}, t)$

- Mathematical Operations

Mathematical Operations

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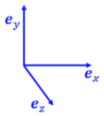


- Divergence

$$\nabla\cdot\boldsymbol{u} = \left(\frac{\partial}{\partial x}\boldsymbol{e}_x + \frac{\partial}{\partial y}\boldsymbol{e}_y + \frac{\partial}{\partial z}\boldsymbol{e}_z\right)(u\boldsymbol{e}_x + v\boldsymbol{e}_y + w\boldsymbol{e}_z) = \left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z}\right)$$

- Discrete approximations

Taylor Series: Discrete Operations

$$\rho(x_{i+1}) = \rho(x_i) + \Delta x_i\left(\frac{\partial\rho}{\partial x}\right)_i + O(\Delta x_i^2)$$

$$\left(\frac{\partial\rho}{\partial x}\right)_i = \frac{\rho(x_{i+1}) - \rho(x_i)}{\Delta x_i} + \frac{1}{\Delta x_i}O(\Delta x_i^2)$$

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$$\left(\frac{\partial\rho}{\partial x}\right)_{i,j} = \frac{\rho_{i+1,j} - \rho_{i-1,j}}{2\Delta x}$$

# Next Session

- Illustration of fluid behavior
  - Deformation, Rotation, …

- Lagrangian & Eulerian Frameworks

- Conservation Laws

# Installations

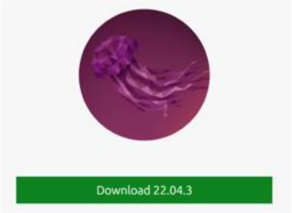
# Required Applications

- Preconfiguration packages:
  - https://1drv.ms/f/s!AqT2YEB97-1RgP8MtsMPqoOGsq4ddg?e=IocXv0
- List
  - Virtual Box [to create virtual machines]
  - Ubuntu 22.04 [OS to install OpenFOAM & Octave]
  - AnyDesk [For remote access]

# Exercises

# Exercise-1 [Due August 29, 2023]

- Operating System:
  - Ubuntu 22.04




- Softwares:
  - OpenFOAM v2306

OpenFOAM®

OpenFOAM-v2306 openfoam

  - Octave

GNU Octave

- Create a github account:
  - https://github.com
  - Discussion forum:
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- Queries
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