Applied Computational Fluid Dynamics using OpenFOAM

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ExaSlate

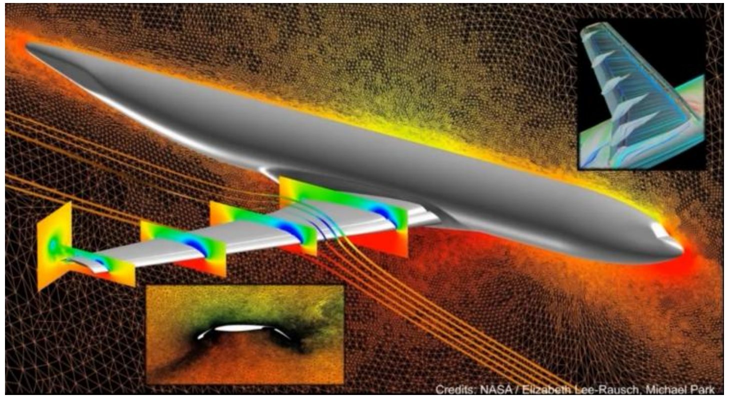
Overview

- Brief introduction
- Continuum Approximation & Governing Equations
- Installation

About this Course

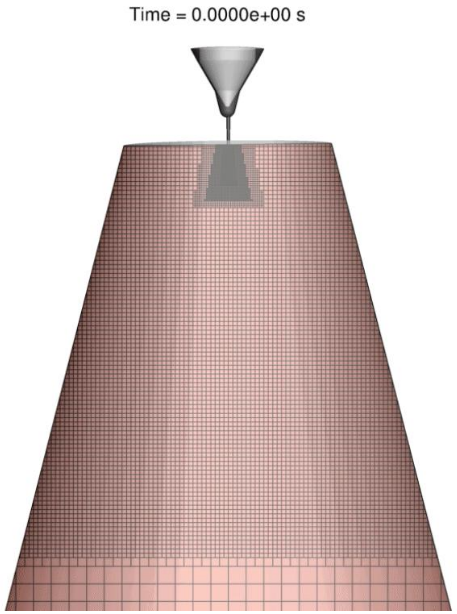
- Course duration per session: 40-60 mins
- Requirements:
  - Virtual box and installing OS & softwares.
  - Interest to learn CFD using OpenFOAM & Octave
  - **Interest to ask questions**
  - **Work as a team**
- Must finish all exercices

Computational Fluid Dynamics



Credit: NASA

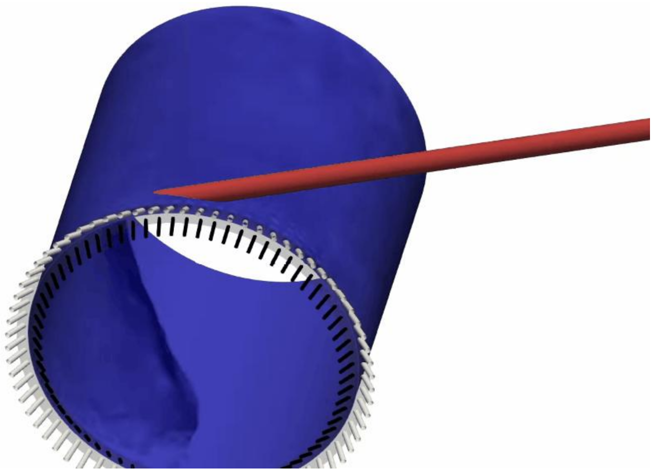
Anumolu (2019)



Anumolu, et al. (2022)

Why CFD?

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



Credit: CSI

Computational Fluid Dynamics (CFD)

References:

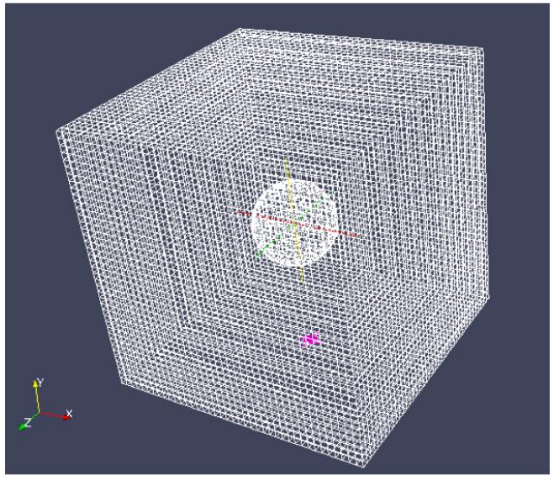
- Ferziger and Peric; Computational Methods for Fluid Dynamics.
- S. Patankar; Numerical Heat Transfer and Fluid Flow.
- Tannehill et al.; Computational Fluid Mechanics and Heat Transfer.
- Versteeg, Malalasekera; An Introduction to Computational Fluid Dynamics.

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

References used for this course:

- *Diversified & interdisciplinary.*

CFD - Workflow



OpenFOAM simulation

Generate mesh

Perform simulation

Post-process results

Tools for this Course

Exercise-1

Install required tools

- Operating System:
  - Ubuntu 24.04

- Softwares:
  - OpenFOAM v2506
  - Octave

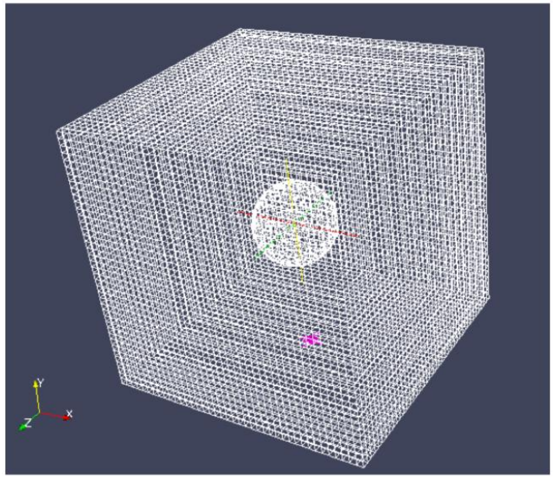
Things TODO by YOU

Exercise-1

Create required accounts

- Create a github account:
  - https://github.com
  - Discussion forum:
    - https://github.com/exaslate-learn/exaslate-training-kct-spring-2026/discussions
- Queries
  - Ask in github discussion forums or WhatsApp group

CFD – Workflow [as an application engineer]



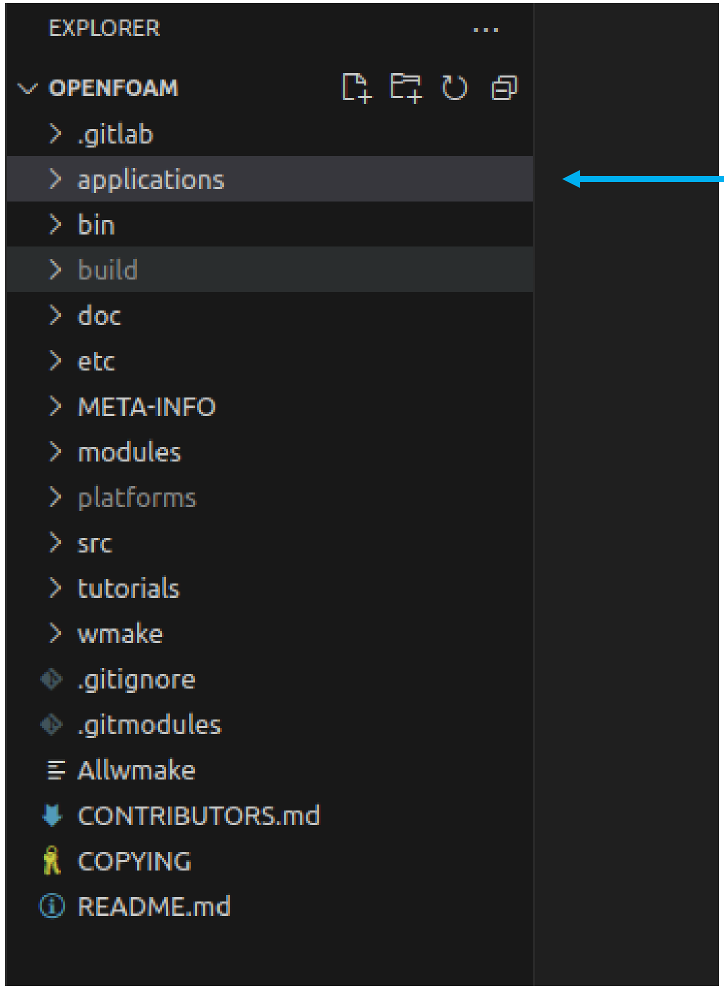
OpenFOAM simulation

Generate mesh

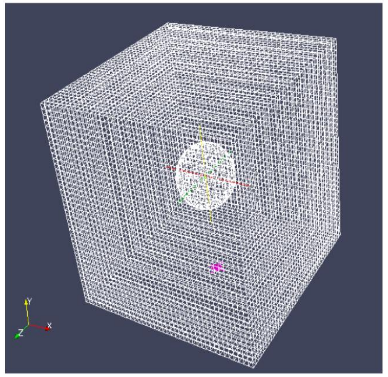
Perform simulation

Post-process results

CFD – Workflow [as a developer]



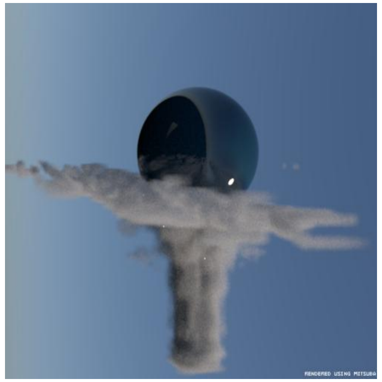
Solvers



Generate mesh

OpenFOAM simulation

Perform simulation



Post-process results

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

Installations

Required Applications

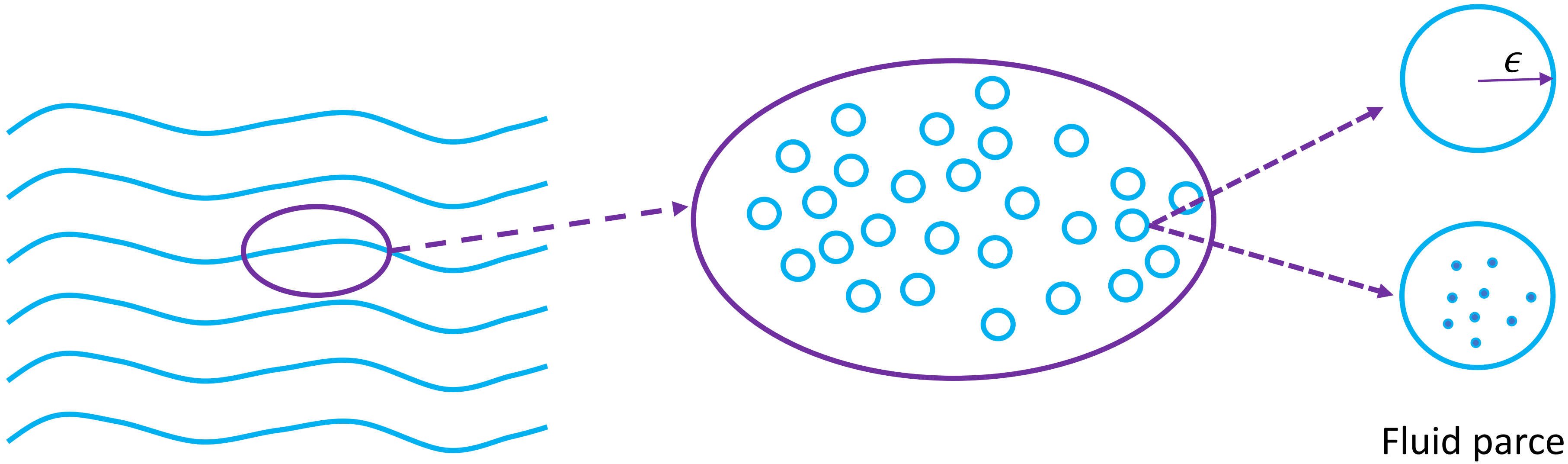
- Preconfiguration packages:
  - https://1drv.ms/f/c/fd1a92e9e59afae0/IgD9WTiWYZMZSJwyFwrMQ-1SAcwEnMMnJKzjgqC1HcRG-oc?e=5uOeMz
- List
  - Virtual Box [to create virtual machines]
  - Ubuntu 24.04 [OS to install OpenFOAM & Octave]
  - AnyDesk [For remote access]

CFD Fundamentals
&
Governing Equations

Fluid

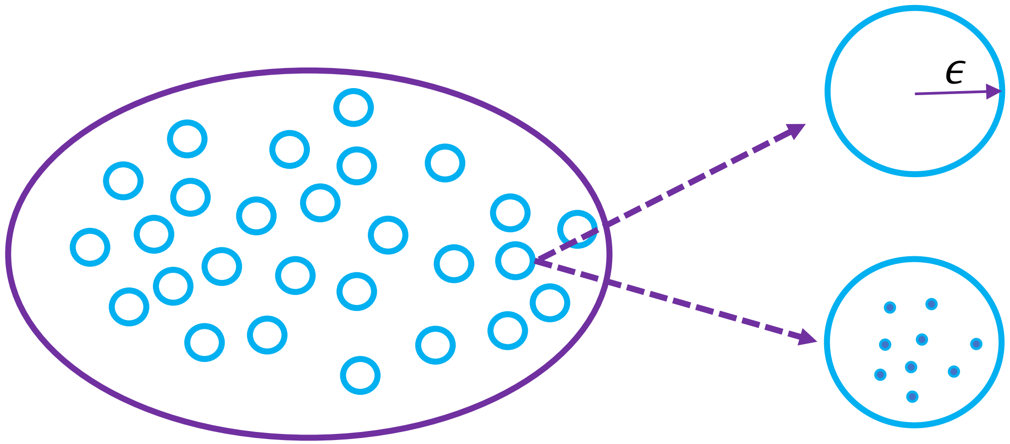
- A substance whose molecular structure offers no resistance to external forces

  \- Ferziger, Peric



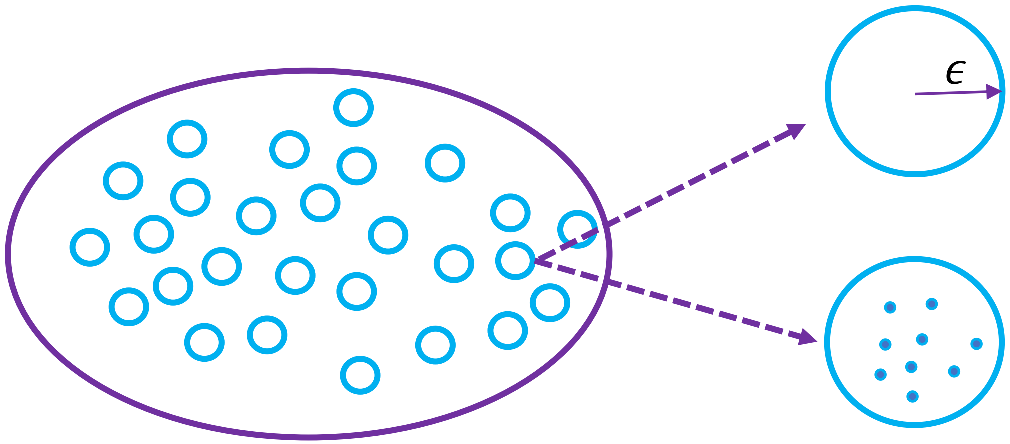
Fluid parcel

Fluid (Continuum)

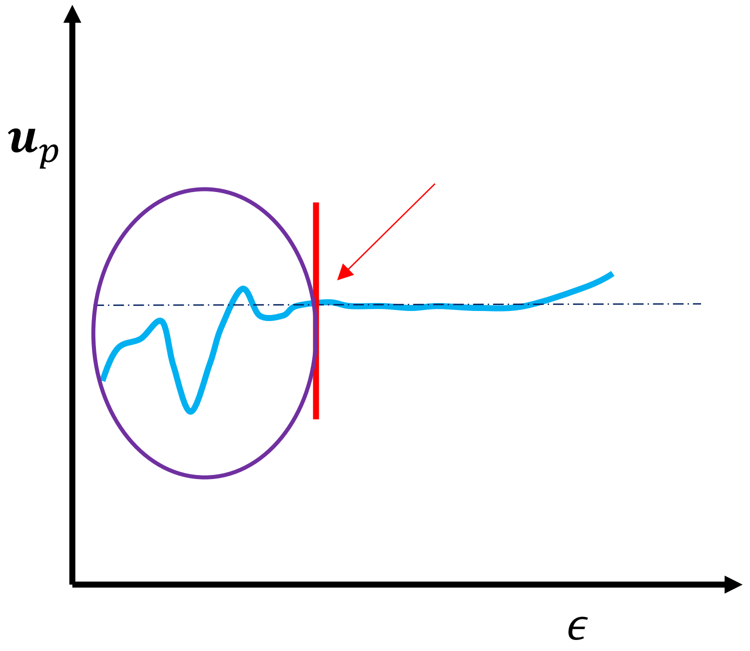


$$\boldsymbol{u}_p = \frac{\sum_{i=1}^{N_{mol}} \boldsymbol{u}_{mol}}{N_{mol}}$$

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

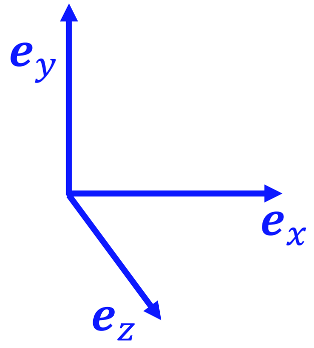
$$\frac{\partial \rho \boldsymbol{u}}{\partial t} + \nabla \cdot (\rho \boldsymbol{u}\boldsymbol{u}) = -\nabla p + \nabla \cdot \boldsymbol{\sigma} + F_b$$

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

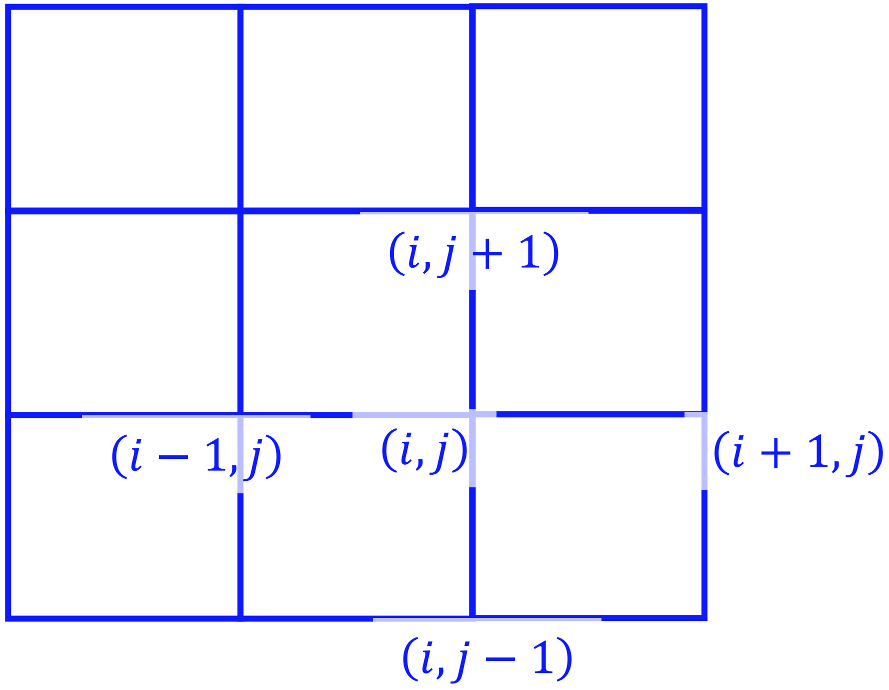
$$\nabla\cdot\boldsymbol{u} = \left(\frac{\partial}{\partial x}\boldsymbol{e}_x + \frac{\partial}{\partial y}\boldsymbol{e}_y + \frac{\partial}{\partial z}\boldsymbol{e}_z\right)(u\boldsymbol{e}_x + v\boldsymbol{e}_y + w\boldsymbol{e}_z) = \left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial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

Discrete Operations

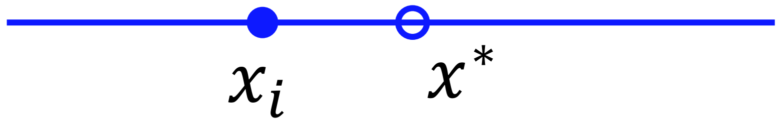
- Finite difference

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

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



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

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

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

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

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

- Finite difference

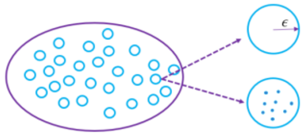
$$\nabla \rho = \left(\frac{\partial}{\partial x}\boldsymbol{e}_x + \frac{\partial}{\partial y}\boldsymbol{e}_y + \frac{\partial}{\partial z}\boldsymbol{e}_z\right)\rho = \left(\frac{\partial \rho}{\partial x}\boldsymbol{e}_x + \frac{\partial \rho}{\partial y}\boldsymbol{e}_y + \frac{\partial \rho}{\partial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

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

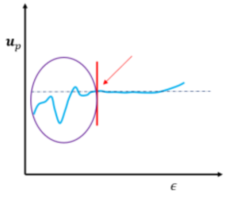
What Did We Discuss?

- Continuum approximation

Fluid (Continuum)



Continuum approximation



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

- Mathematical Operations

Mathematical Operations

- Gradient

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

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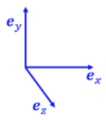

- Divergence

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- 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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- Finite difference

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

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

Next Session

- Finish OpenFOAM setup
- How to perform simulation using OpenFOAM?

Exercises

Exercise-1

- https://github.com/exaslate-learn/exaslate-training-kct-spring-2026/discussions/2