OpenFOAM 2206 Lecture 00 Introduction

汪洋
wangyangstayfoolish@gmail.com

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Overview

- Computational Fluid Dynamics，计算流体动力学
- Physical model, 物理模型
- Programming，计算机编程
- Operating systems，操作系统
- Software, 应用软件

计算流体动力学

- book

F. Moukalled L. Mangani M. Darwish
The Finite Volume Method in Computational Fluid Dynamics
An Advanced Introduction with OpenFOAM® and Matlab

H K Versteeg and W Malalasekera
An Introduction to Computational Fluid Dynamics
THE FINITE VOLUME METHOD

Sandip Mazumder
Numerical Methods for Partial Differential Equations
Finite Difference and Finite Volume Methods

Jasak, Hrvoje
Error analysis and estimation for the finite volume method with applications to fluid flows.
Imperial College London University of London, 1996.

计算流体动力学

- 理解不可压守恒型 N-S 方程

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{U}) = 0 \tag{1}$$

$$\begin{aligned}\frac{\partial (\rho \mathbf{U})}{\partial t} + \nabla \cdot (\rho \mathbf{U}\mathbf{U}) = &-\nabla p + \nabla \cdot \left(\mu \left((\nabla \mathbf{U}) + (\nabla \mathbf{U})^T\right)\right) \\ &- \frac{2}{3}\mu (\nabla \cdot \mathbf{U}) \mathbf{I} + \rho \mathbf{g} + \mathbf{S}\end{aligned} \tag{2}$$

- 理解由此对应的内容 积分形式、微分形式，守恒形式和不守恒形式。思考为什么会出现有限体积法 。
- 理解网格、离散、系数矩阵、代数方程组求解

一点点可压

- Burgers 方程

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} = 0 \tag{3}$$

$$\frac{\partial u}{\partial t} + c\frac{\partial u}{\partial x} = 0 \tag{4}$$

它们也很意思，客观说，培养和水平可压的要高一些。

分析过程

- 物理模型和数学方程
  - 通过数学工具来描述自然界的物理现象
- 连续和离散
  - 连续的几何和离散的点
- 边界条件
  - 三类边界条件
- PDE 方程求解
  - 解析解
  - 数值解
- 求解稀疏矩阵方程组
  - 直接法
  - 间接法

有限体积法

$$\underbrace{\int_V [\nabla \cdot (\mathbf{UU})] dV}_{convection\ term} = \underbrace{-\int_V \frac{\nabla p}{\rho} dV}_{grad\ p} + \underbrace{\int_V \nabla \cdot (\mu \nabla \mathbf{U}) dV}_{diffusion\ term} + \underbrace{\int_V \mathbf{g} dV}_{source\ term} \tag{5}$$

- 网格划分
- 边界条件确定
- 求解精度选取
- 离散数值格式选取
- 显式与隐式妥协

网格

- 结构化网格
- 非结构化网格

各项离散格式

- 扩散项
- 梯度项
- 对流项
- 时间项
- 源项

代数方程组求解

- Direct method 直接法
  - 消元法
  - LU 分解
- Iterative method 迭代法，间接法
  - Conjugate Gradient 共轭梯度
  - Multigrid 多重网格

应用软件

- OpenFOAM
- fluent
- Star CCM+
- COMSOL
- in house code

OpenFOAM 例子

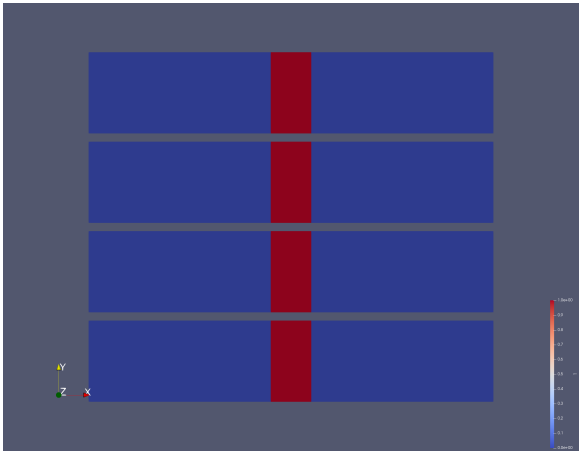
- 一维标量输运方程

$$\frac{\partial T}{\partial t} + \mathbf{U} \cdot \nabla T = \Gamma \frac{\partial^2 T}{\partial x^2} \tag{6}$$

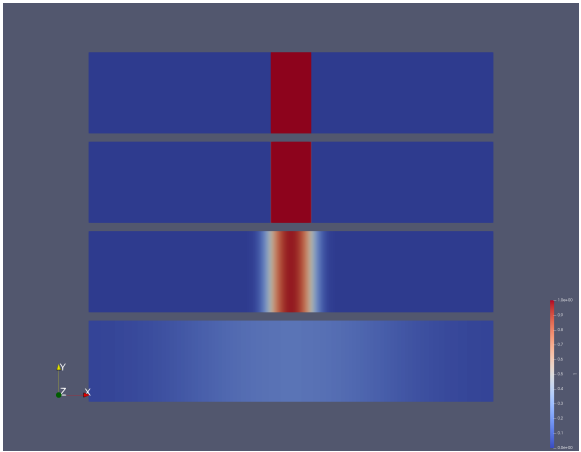
case

No	U[m/s]	Γ	transport equation
1	(0 0 0)	$1e^{-6}$	$\frac{\partial \mathrm{T}}{\partial \mathrm{t}} = \Gamma \frac{\partial^2 \mathrm{T}}{\partial \mathrm{x}}$
2	(0 0 0)	$1e^{-4}$	
3	(0 0 0)	$1e^{-2}$	
4	(0 0 0)	$1e^{0}$	
5	(1 0 0)	0	$\frac{\partial \mathrm{T}}{\partial \mathrm{t}} + \mathbf{U} \cdot \nabla \mathrm{T} = 0$
6	(0.5 0 0)	0	
7	(2 0 0)	0	
8	(1 0 0)	$1e^{-6}$	$\frac{\partial \mathrm{T}}{\partial \mathrm{t}} + \mathbf{U} \cdot \nabla \mathrm{T} = \Gamma \frac{\partial^2 \mathrm{T}}{\partial \mathrm{x}}$
9	(1 0 0)	$1e^{-4}$	
10	(1 0 0)	$1e^{-2}$	
11	(1 0 0)	$1e^{0}$	

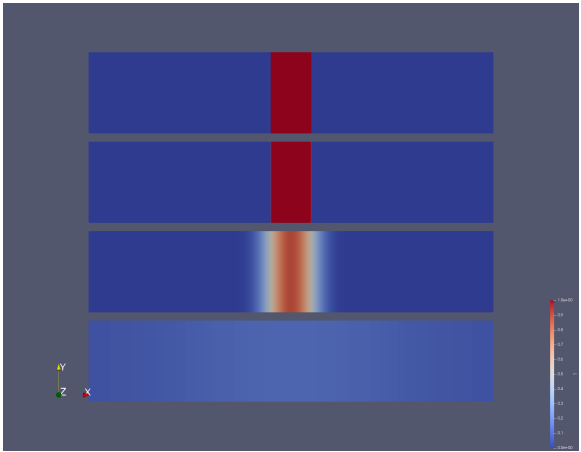
case1-4initial



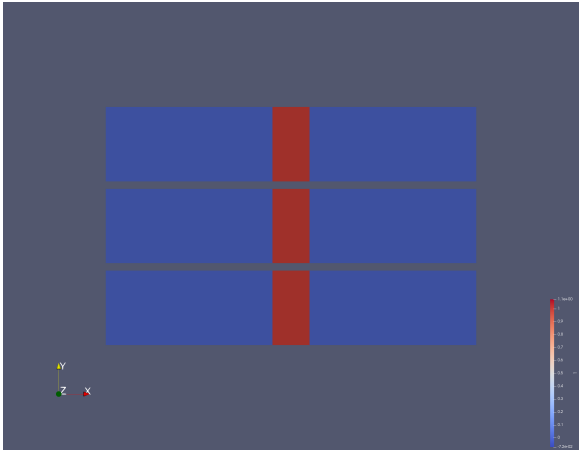
case1-4middle



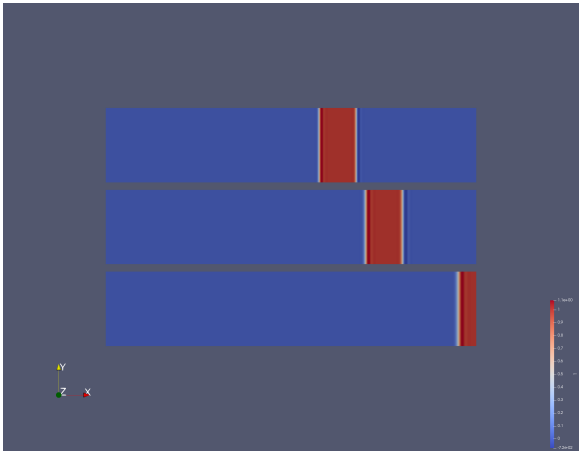
case1-4ending



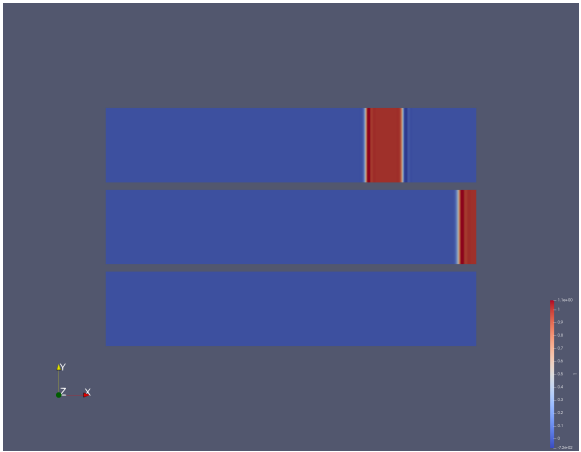
case5-7initial



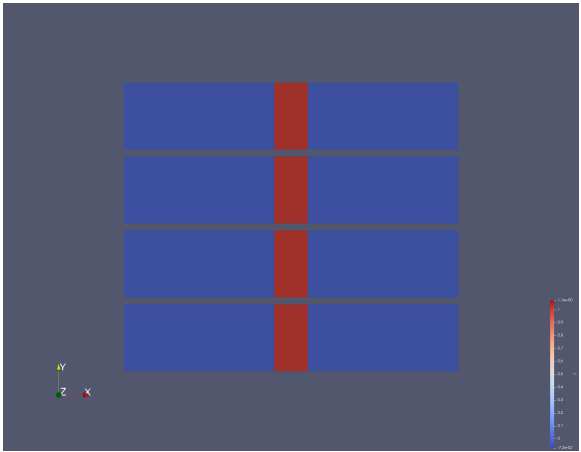
case5-7middle



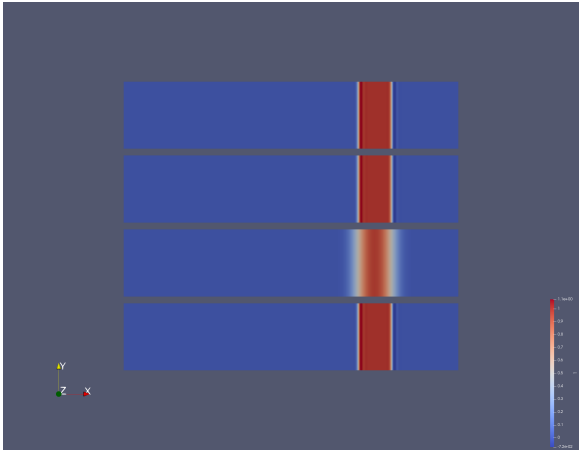
case5-7ending



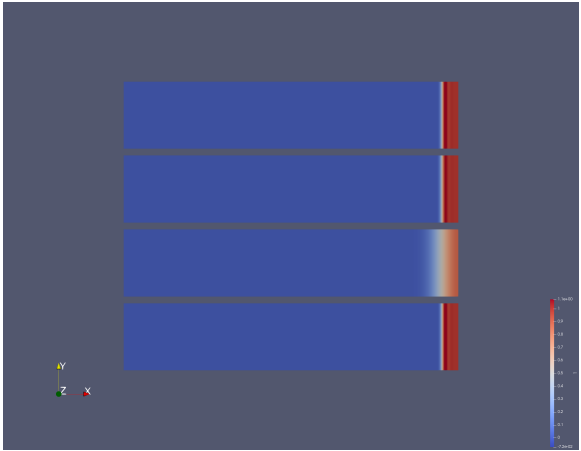
case8-11initial



case8-11middle



case8-11ending



致谢

非常感谢!