EX18402（東京工業大学推薦課題）

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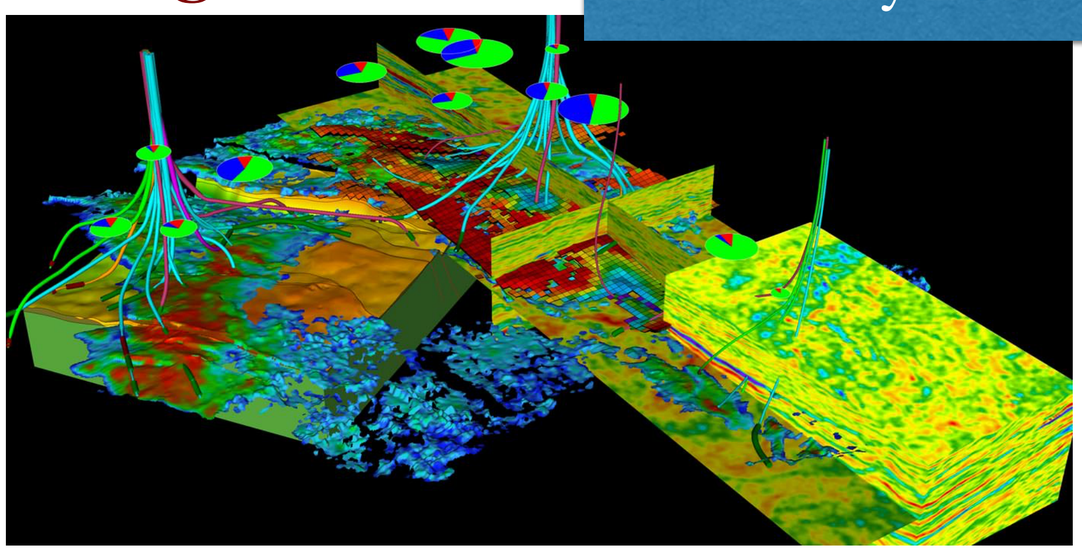
多孔質媒体流れ解析を用いた低塩分濃度水による石油増進メカニズムの解明

Background

Low salinity EOR



- Low salinity EOR(Enhanced Oil Recovery) is a cost-effective and environmentally friendly technique for improved oil recovery.
- Difficulties in predicting the oil recovery efficiency.
- Reservoir simulations used to predict the performance of oil and gas reservoirs under different recovery schemes, always need relevant multiphase flow properties (Relative permeability, capillary pressure curve, etc)
- It is difficult and extremely time consuming to measure the properties.
- Pore scale numerical simulations to reveal the complex flow behavior and predict those physical properties are required.

Multi-phase Lattice Boltzmann Model

Distribution functions

$$f_i^k(\mathbf{x}+\mathbf{e}_i\delta t, t+\delta t) = f_i^k(\mathbf{x},t) + \Omega_i^k(\mathbf{x},t)$$

K denotes the different phase

$$\Omega_i^k = (\Omega_i^k)^{(3)}\left[(\Omega_i^k)^{(1)} + (\Omega_i^k)^{(2)}\right]$$

Collision operator

$$(\Omega_i^k)^{(1)}(f_i^k) = f_i^k - \mathbf{M}^{-1}\mathbf{S}\mathbf{M}\left(f_i^k - f_i^{k,eq}\right)$$

→ multiple-relaxation-time (MRT) operator for viscosity term [d' Humieres, 1994]

$$(\Omega_i^k)^{(2)}(f_i^k) = f_i^k + \sum_{l,l\neq k}\frac{A_{kl}}{2}\left|\mathbf{G}_{kl}\right|\left[W_i\frac{(\mathbf{G}_{kl}\cdot\mathbf{e}_i)^2}{|\mathbf{G}_{kl}|^2} - B_i\right]$$

→ perturbation operator for interfacial tension term [Reis and Phillips, 2007]

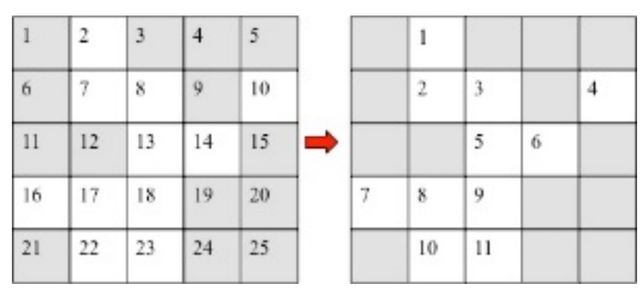
$$(\Omega_i^k)^{(3)}(f_i^k) = \frac{\rho_k}{\rho}f_i^* + \sum_{l,l\neq k}\beta_{kl}\frac{\rho_k\rho_l}{\rho^2}\cos(\varphi_i^{kl})f_i^e(\rho,0,\overline{\alpha}|_{q=1})$$

→ recoloring operator to promote phase segregation [Latva-Kokko and Rothman, 2005].

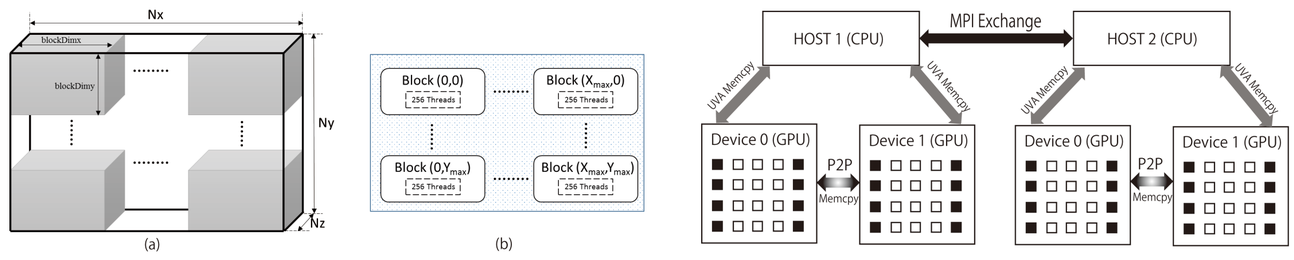
Multi-GPU Implementation

❑ **Optimized for porous media, powerful and efficient than any multiphase commercial software**

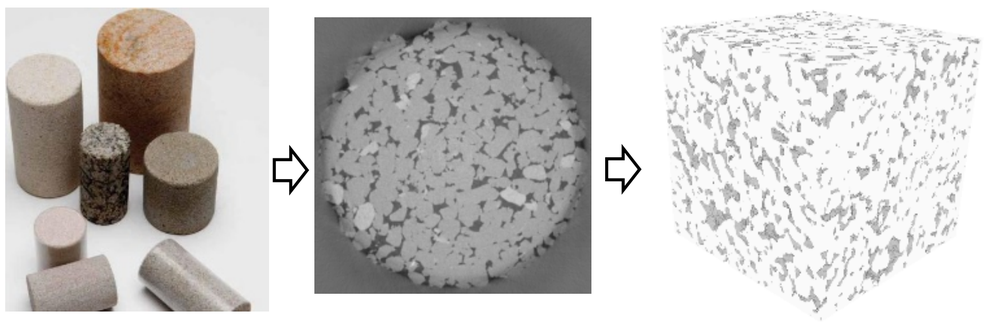
- *Sparse storage method*
  Solid mesh information is not stored
- *GPU CUDA cores parallelization*
  Domain distribution in the CUDA framework.
- *Multi-GPU parallelization*



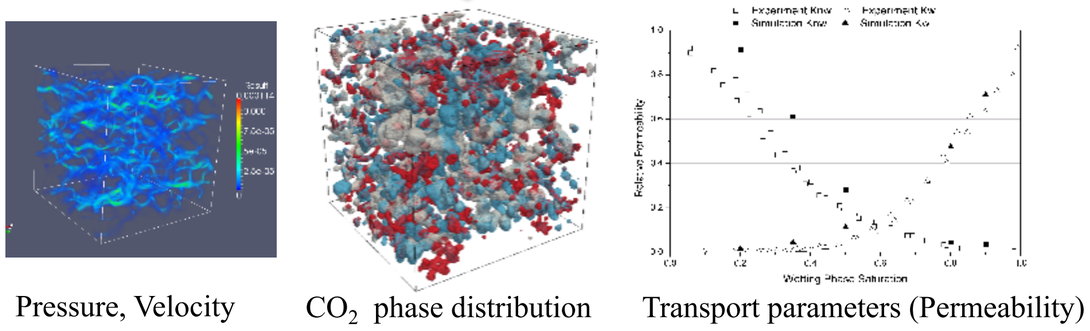
Communication scheme showing data transfer between different GPU boards



Digital Rock Approach



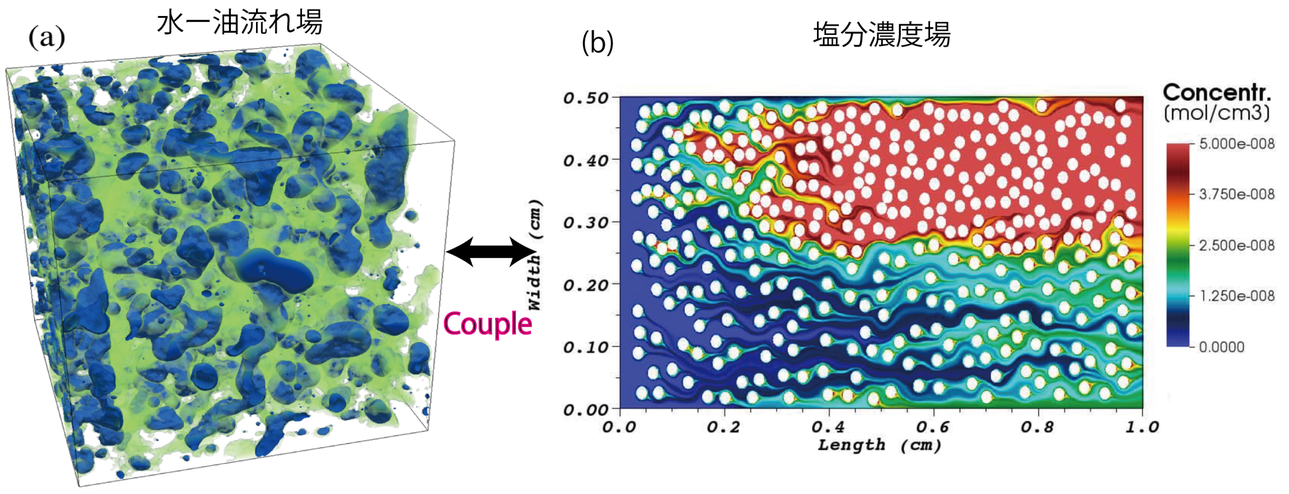
Reservoir cores　CT image　Digital rock sample



Pressure, Velocity　CO_2 phase distribution　Transport parameters (Permeability)

Development of pore scale model for LS-EOR

- Solve flow field by the two-phase LBM
- Transport concentration of salinity as a passive scalar quantity
- Change of the wettability toward water-wet by the low-salinity water



Large Scale Computation

Heterogeneous Carbonate

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REV (Representative Elementary Volume) Size is extremely large

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High resolution is required for micro pore

↓

System Size (1000*1000*1000 meshes)

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Large scale calculation
Over1 billion meshes

Reference: Fei Jiang, Takeshi Tsuji Estimation of three-phase relative permeability by simulating fluid dynamics directly on rock-microstructure images, Water Resoures Research, Volume 53, Issue 1 January, 2017, Pages 11-32