Steady Flow Prediction using Convolutional Neural Networks with Boundary Exchange

Sora Hatayama
Graduate School of Engineering, The University of Tokyo

Takashi Shimokawabe
Information Technology Center, The University of Tokyo

1.Background

Computational fluid dynamics (CFD) are widely used as a fluid analysis technique. However, these have two problems.

- **Expensive calculation cost**
- **Long calculation time**

we provide the method and implementation of **steady flow prediction using convolutional neural networks (CNN) with boundary exchange** , and show the predicting results of this method and lattice Boltzman method soulutions.

2. Lattice Boltzmann Method (LBM)

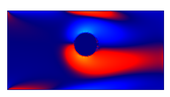
- Solving time evolution equation of particle distribution function
- One of the CFD analysis which is used for simulating steady flow

Navier-Stokes equation
(Governing equation of fluid)

Discretize

LBM

$$f_i(x + e_i\Delta t, t + \Delta t) = \underbrace{f_i(x,t)}_{\text{streaming}} + \underbrace{\frac{1}{\tau}\left[f_i^{(0)}(x,t) - f_i(x,t)\right]}_{\text{collisions}}$$



Lattice Bhatnagar Gross Krook Equasion

3. Signed Distance Function (SDF)

- A universal representation for different geometry shapes and works efficiently with neural networks

$$D(i,j) = \underbrace{\min_{(i',j')\in Z} \left|(i,j) - (i',j')\right|}_{①} \underbrace{\text{sign}(f(i,j))}_{②}$$

① : distance
② : levelset function $f(i,j)$

$$\begin{cases} f(i,j) = 0 & \text{if and only if } (i,j) \textit{ is on the geometry boundary} \\ f(i,j) > 0 & \text{if and only if } (i,j) \textit{ is outside the geometry} \\ f(i,j) < 0 & \text{if and only if } (i,j) \textit{ is inside the geometry} \end{cases}$$

4. Convolutional Neural Networks (CNN)

- Neural networks with convolutional layers
- Feature extraction based on regions instead of points
- Convolution makes the network robust to moving and changing images.

5. Proposed Method

① Build a CNN model that predicts the results of a single region of the steady flow that is a certain fixed size (256×128)

② Predict a larger area than a single network can handle by using boundary exchange together with a single area CNN.

6.1 CNN Model

Input
- signed distance function (SDF)
- boundary condition

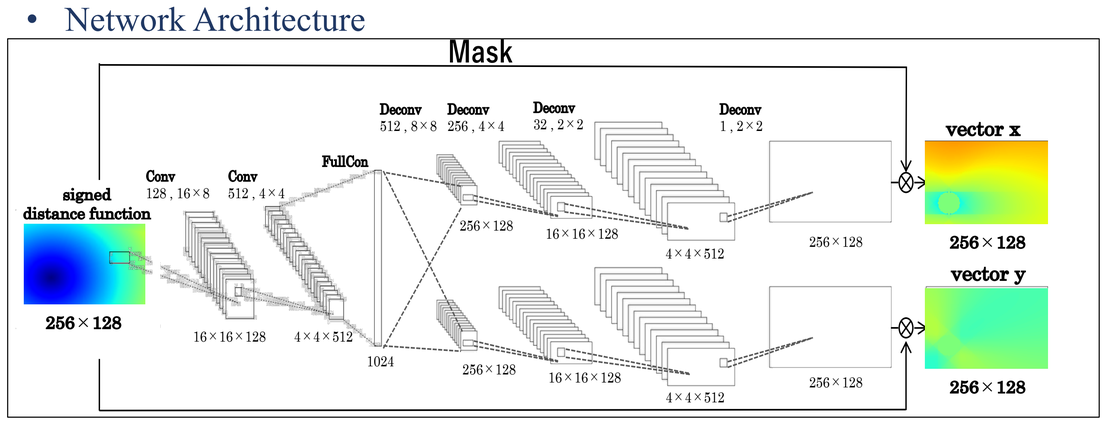
→ Neural Network →

Output
Prediction of Lattice Boltzmann Method (LBM)

- Parameter

Batch size	64	Initialize	Xavier
Learning rate	0.0001	Epoch	1000
Activation function	ReLU	Caliculation time	24 min.
Optimizer	Adam		

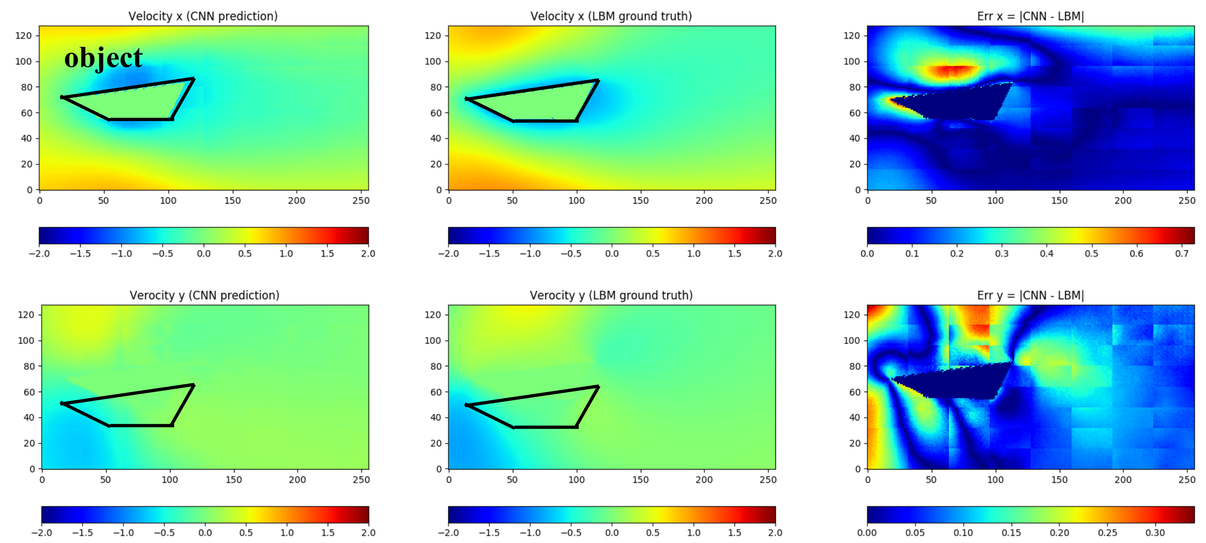
- Network Architecture



- Device : Reedbush, 2nodes (8 GPUs), Tesla P-100
- Environment : Chainer 6.4.0, Chainer MN 1.2.0, CUDA 9.1.85
- Dataset : 512 randomly placed cylinders, triangles, quadrilateral, pentagon of various sizes in a 256 x 128 area (total …6144, training … 4608 ,validation …1536)

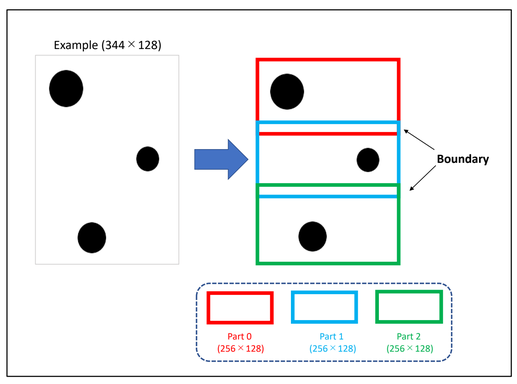
6.2 Result

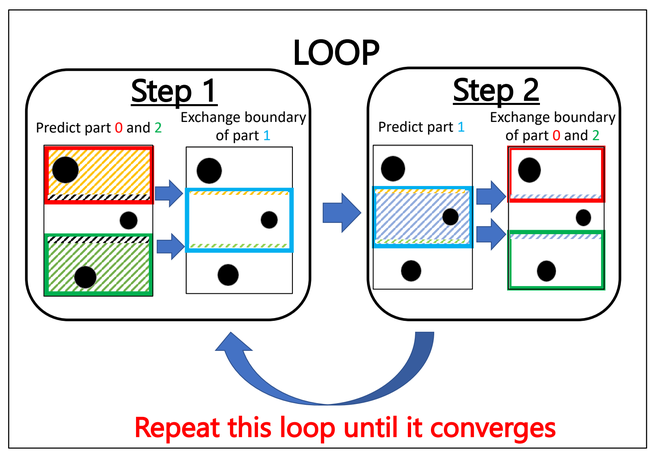
- Loss of the proposed CNN model is very **low** (0.000115) and it can reduce the calculation time by **99%** (LBM : 13.800 s, CNN : 0.006s)



7.1 Prediction using Boundary Exchange

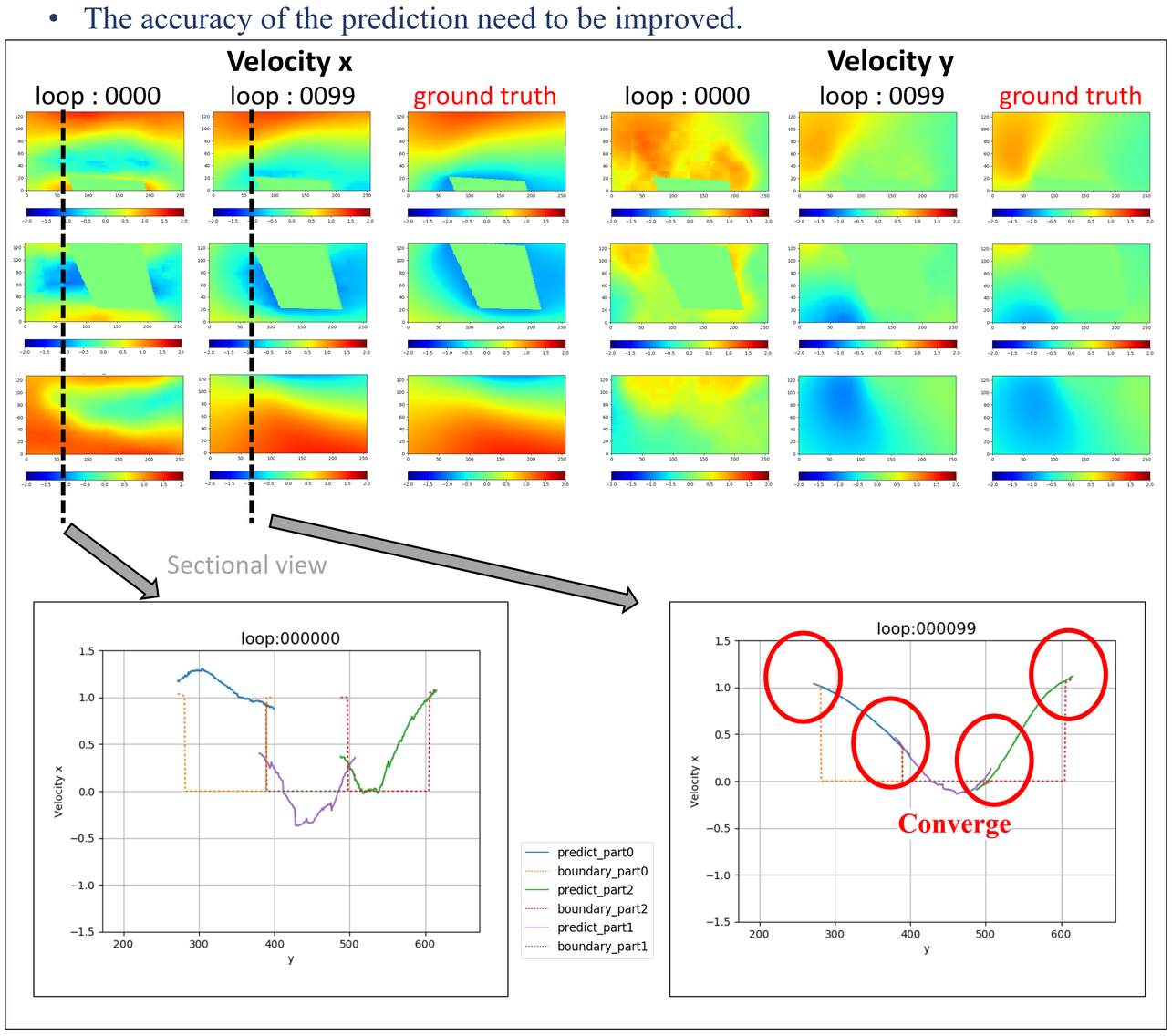
- The prediction area is devided into 256 × 128 areas (overlapped 20 width)
- The prediction is performed for each and repeated **until the overlapping portion, which is the boundary, converges (utilizing the properties of the CFD)**





7.2 Result

- The initial prediction is corrected by repeatedly applying the proposed method, and it approaches the ground truth.
- The accuracy of the prediction need to be improved.



8. Conclusion

In this poster, we provide the method and implementation of steady flow prediction using CNN with boundary exchange and show the predicting results of this method and LBM solutions. The proposed CNN model, which predicts the results of a single region of the steady flow, enables high accuracy prediction of LBM result and reduces calculation time by 99%. Prediction using Boundary Exchange for wide area is effective, but the accuracy need to be improved.We will improve the generalization of the model by increasing the pattern of datasets.