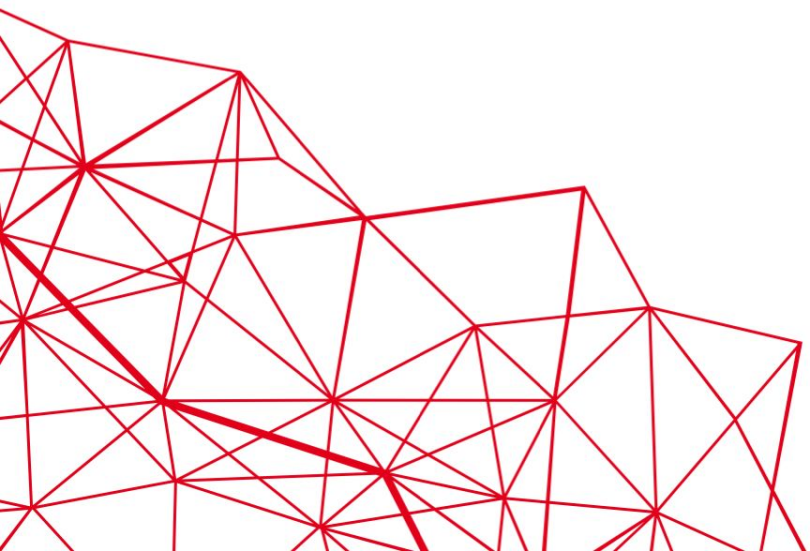

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Complete Deep Computer-Vision Methodology for Investigating Hydrodynamic Instabilities

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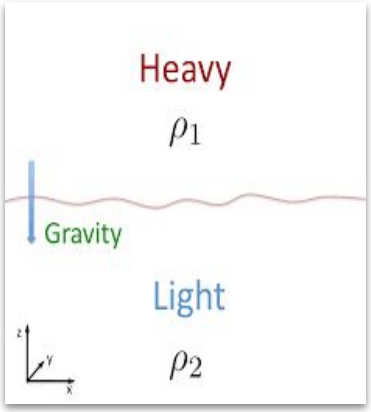
הוועדה לאנרגיה אטומית
Israel Atomic Energy Commission

Rayleigh-Taylor Instability

Computational Fluid Dynamics

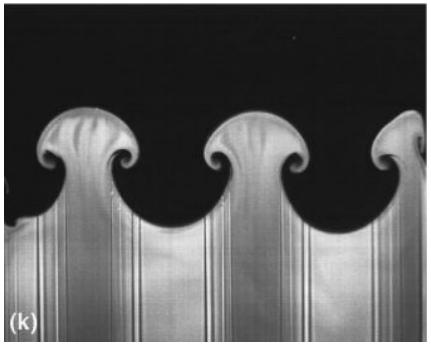
Rayleigh-Taylor Instability

CFD is an essential tool for investigating hydrodynamic instabilities



$$e^{\sqrt{\mathcal{A}kg}T}$$

$$k = 2\pi/\lambda, \quad \mathcal{A} = \frac{\rho_1 - \rho_2}{\rho_1 + \rho_2}$$

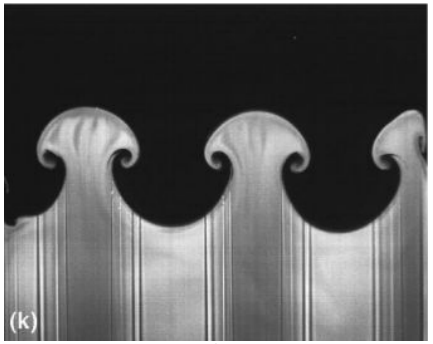


RTI experiment by Waddell et al 2001.

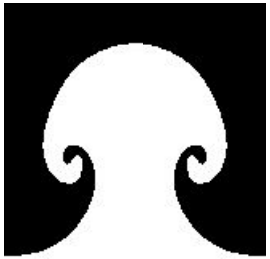
Hydrodynamic Instabilities - Experiments vs. Simulation

Many experiments are being conducted in order to study the growth of the instability.

Experiment



Gap



Simulation

Bridging the gap

With CVDL

Key Problems that will enhance our understanding of Hydrodynamic Instabilities

Input		Output
1. Image from an experiment or simulation	→	Sort a database using similarity score
2. Image from an experiment or simulation	→	Extract the initial parameters
3. Partial template	→	Sort a database using similarity score
4. Set of images that corresponds to a set of timsteps	→	Prediction of future from non-existing times

Specifications towards *RayleAI*

Database of Rayleigh-Taylor instability images.
~130k images

https://github.com/scientific-computing-nrcn/SimulAI.

Input parameters

=

Parameter	From	To	Stride
Atwood number($\mathcal{A}$)	0.02	0.5	0.02
Gravity (g) [cm/s^2]	600	800	25
Amplitude (h) [cm]	0.1	0.5	0.1
X [cm]	2.7	2.7	0.0
Y [cm]	5.4	5.4	0.0

↓

Hydrodynamic code - DAFNA

↓

Simulation images

Evaluating the Solutions

Evaluation Methodology

Physical Loss = how physically meaningful the results of the technique are.

Error Function

Input parameters

Output parameters

$$PhysicalLoss = \frac{Input - Output}{Output}$$

Bridging the gap

Task #1 - Image retrieval

Task I: Image retrieval

From an image of an experiment to the closest image from the database

Input

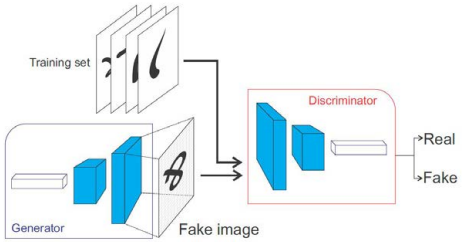
Image from a simulation or experiment

Output

Sort a database using similarity score

Possible solution

Computer Vision and/or Machine Learning

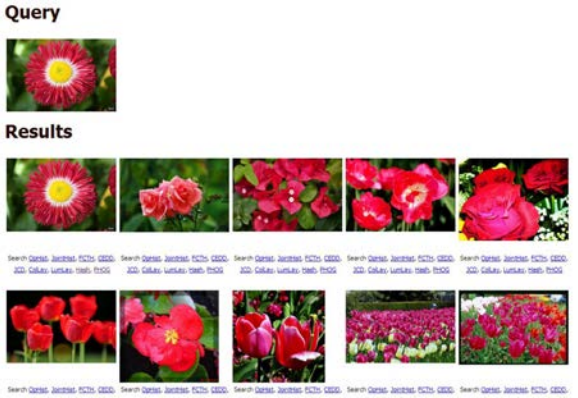


Task I: Image retrieval - LIRE

LIRE - Lucene Image Retrieval

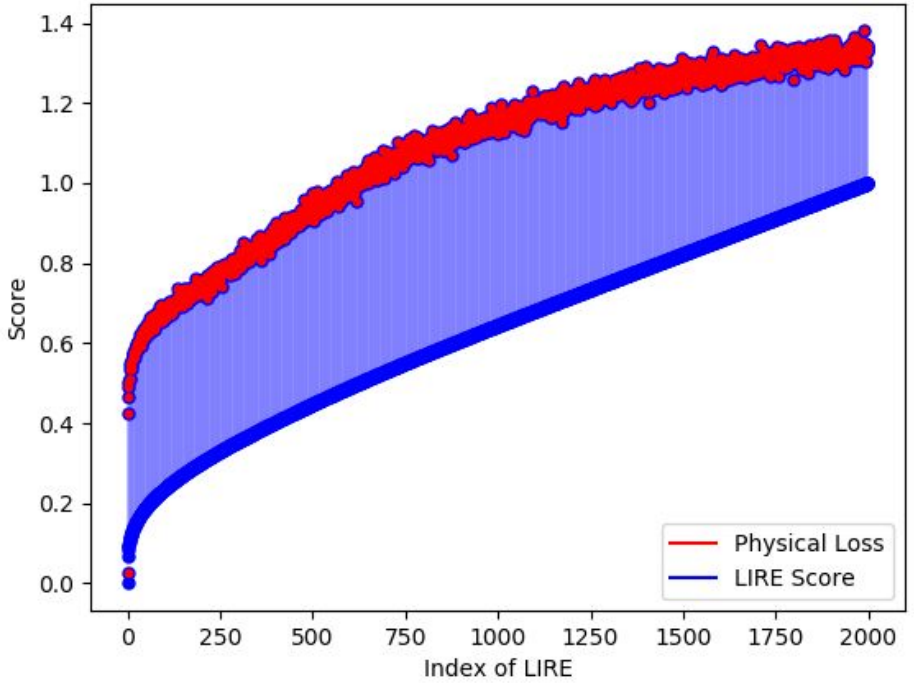
- **LIRE** is a Java library that provides a simple way to retrieve images based on color and texture characteristics.

- **LIRE** creates a Lucene index of image features for content based image retrieval (CBIR) using local and global **state-of-the-art** methods.



Task I: Image retrieval - LIRE

The ***physical loss*** of Atwood number.

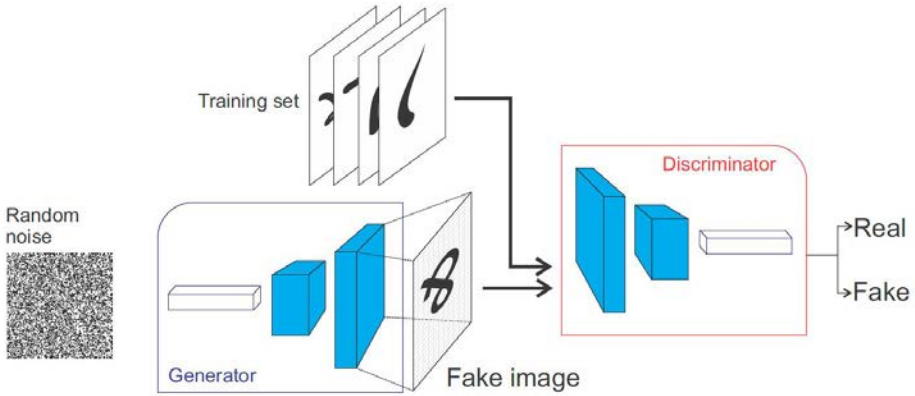


LIRE scores on **random** set of images.

Task I: Image retrieval - InfoGAN

Similarity using high abstract level representation distance

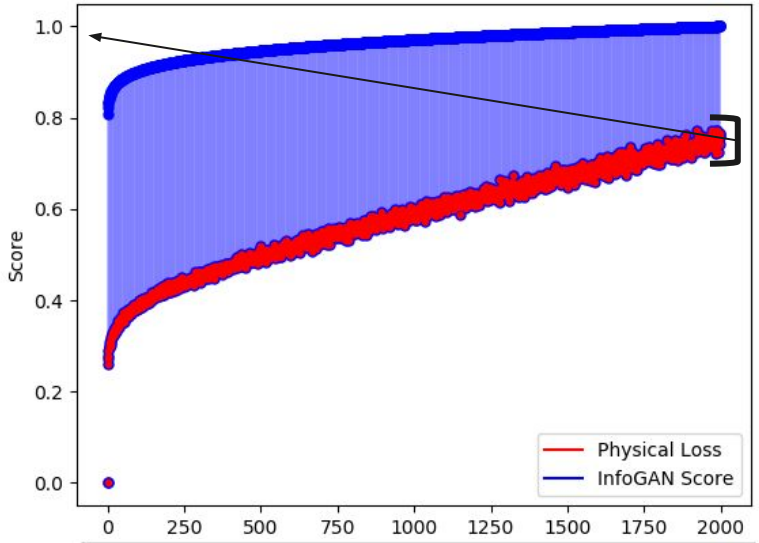
Generative Adversarial Network (**GAN**) learns *generator* **G** that generates images that are similar to the original ones, and *discriminator* **D** that distinguishes generated images from real ones.



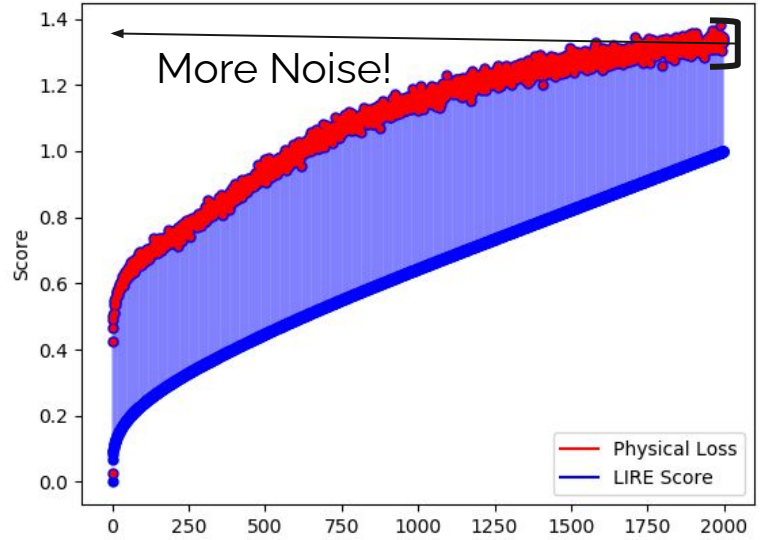
Task I: Image retrieval - InfoGAN

InfoGAN vs. LIRE scores on random set of images on Atwood number.

InfoGAN



LIRE



Bridging the gap

Task #2 - Parameter Regression

Task 2: Parameters Regression - pReg

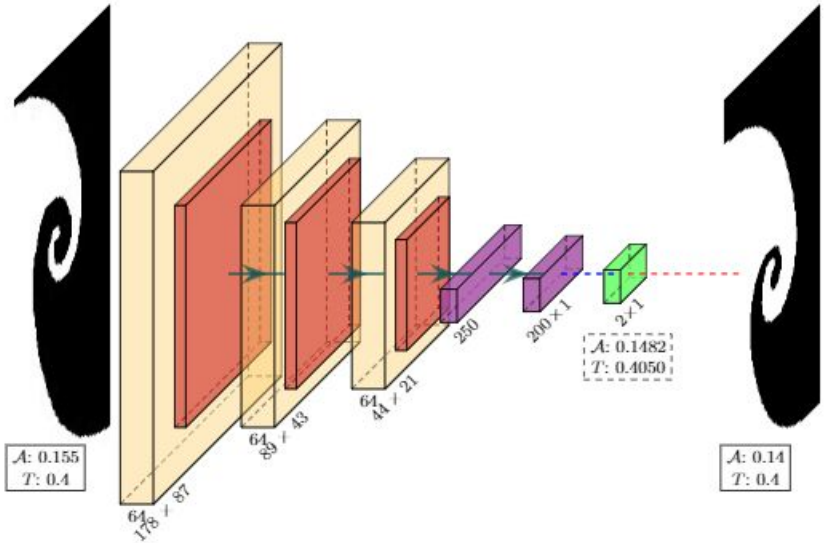
Estimating the initial parameters using CNN

Input

Image with unknown parameters

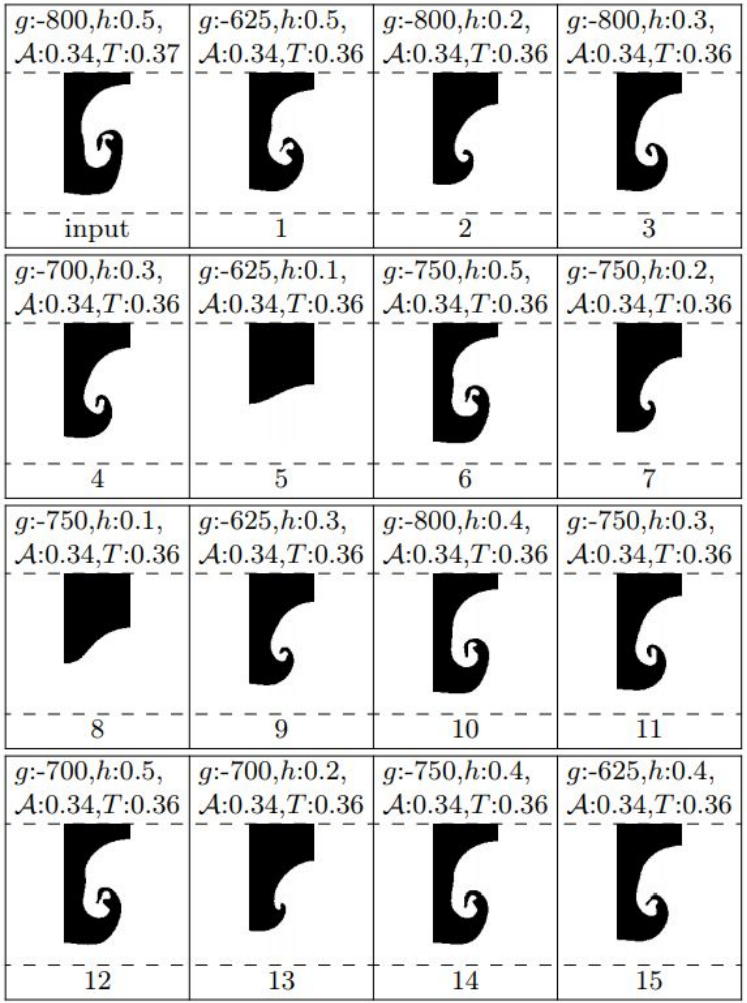
Output

Parameter estimation via ConvNet



Task 2: Image retrieval - pReg

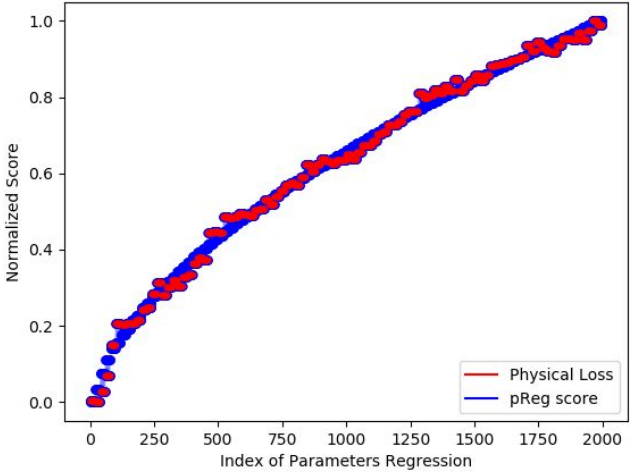
Results



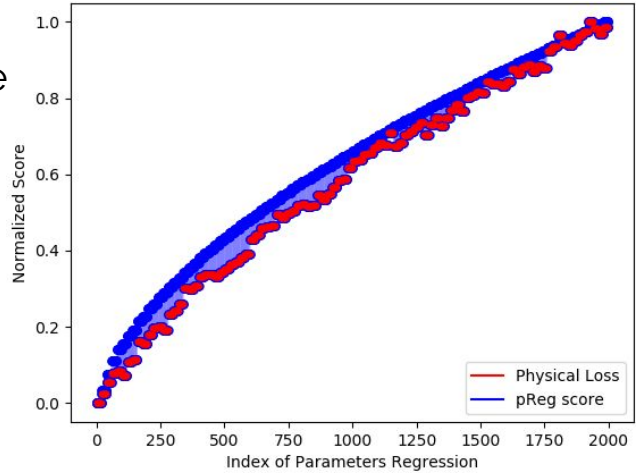
Task 2: Image retrieval - pReg

Results

1. **Atwood** number average score.



2. **Time** average score.



Bridging the gap

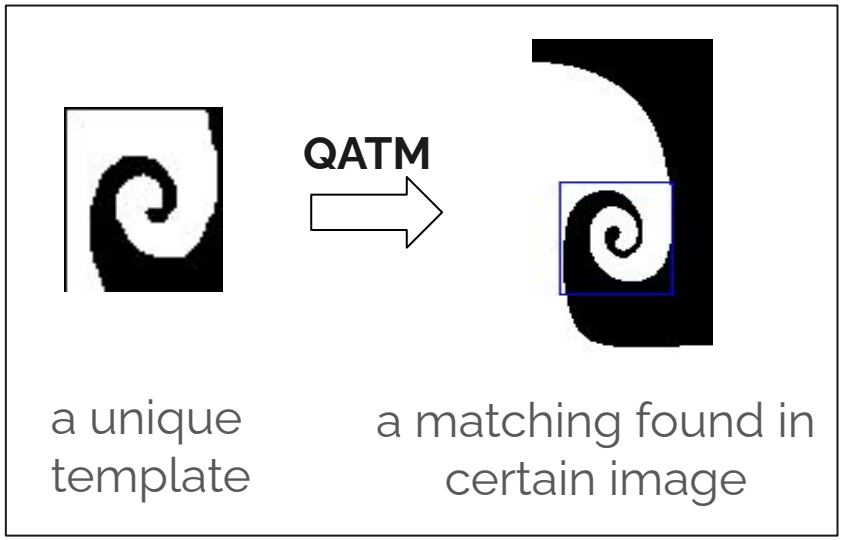
Task #3 - Image retrieval from Partial Template

Task 3: Partial Template Matching - QATM

Quality-Aware Template Matching using QATM

- The Quality-Aware Template Matching (**QATM**) algorithm is inspired by assessing the **matching quality** of source and target patches.

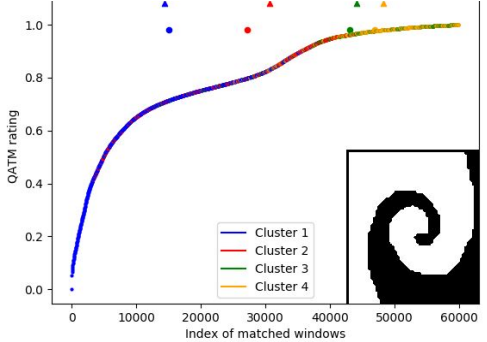
- The algorithm takes the **uniqueness** of pairs into consideration rather than simply evaluating matching score.



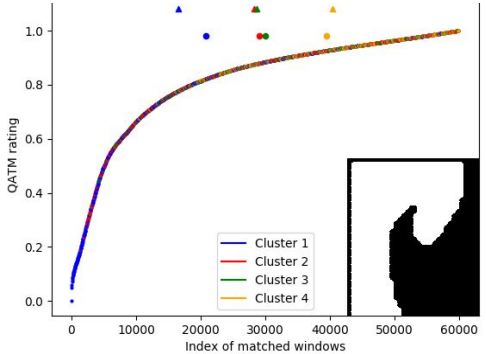
Task 3: Partial Template Matching - QATM

Results

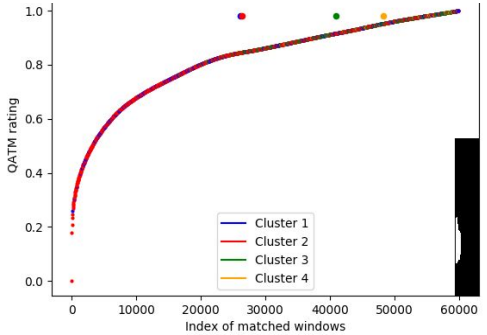
1. QATM scores and clustering results on a **unique** template



2. QATM scores and clustering results on a **semi-unique** template



3. QATM scores and clustering results on a **non-unique** template



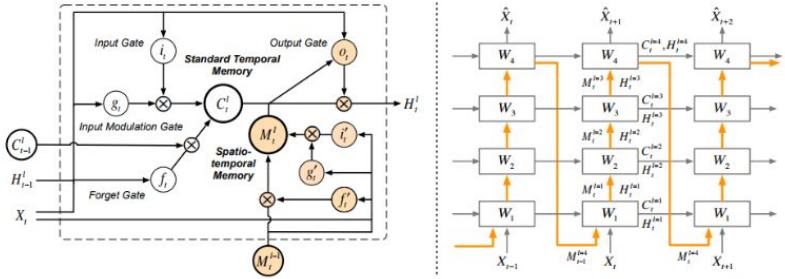
Bridging the gap

Task #4 - Time-series prediction

Task 4: Time Series Prediction - PredRNN

Predictive Recurrent Neural-Network

PredRNN - Convolutional Long Short Term Memory networks for time-series prediction



Input

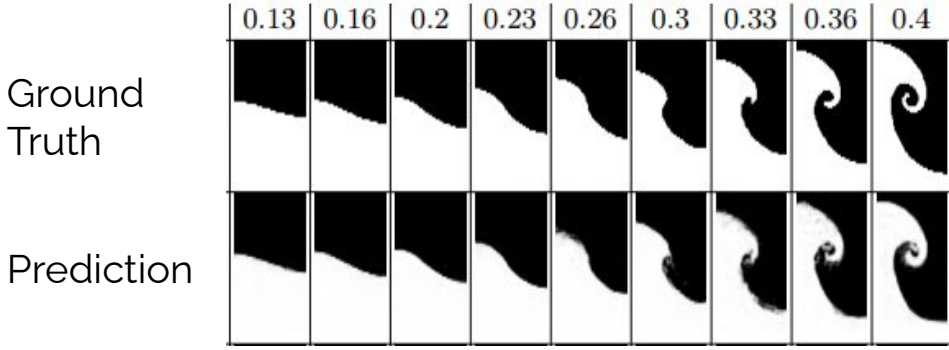
Multiple images that present a time-series

Output

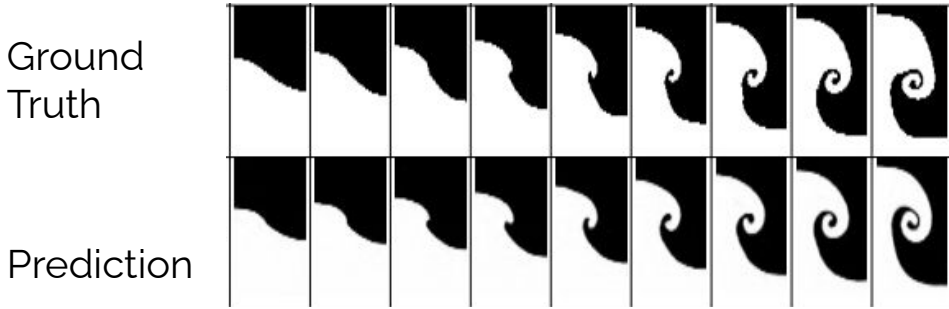
The next 'predicted' time-step

Task 4: Time Series Prediction - PredRNN

Results



Time-step prediction by PredRNN, on **experiment images**.



Time-step prediction by PredRNN, on **simulation images**.

Conclusions & Future work

Conclusions

- What is Rayleigh-Taylor Instability?
- The key problems were defined.
- ***RayleAI*** - A comprehensive tagged database and specification was introduced.
- Demonstration of the CVDL techniques on RTI.
- ***Physical Loss*** evaluation methodology is presented.
- In all four tasks, excellent results were achieved!

Future Work

- An extension of the methodology that will solve the problem when the parameters of the experiment is not included in the database.
- Testing the same techniques on a different database of a different physical instability.
- Explainable AI (XAI) methodology.

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