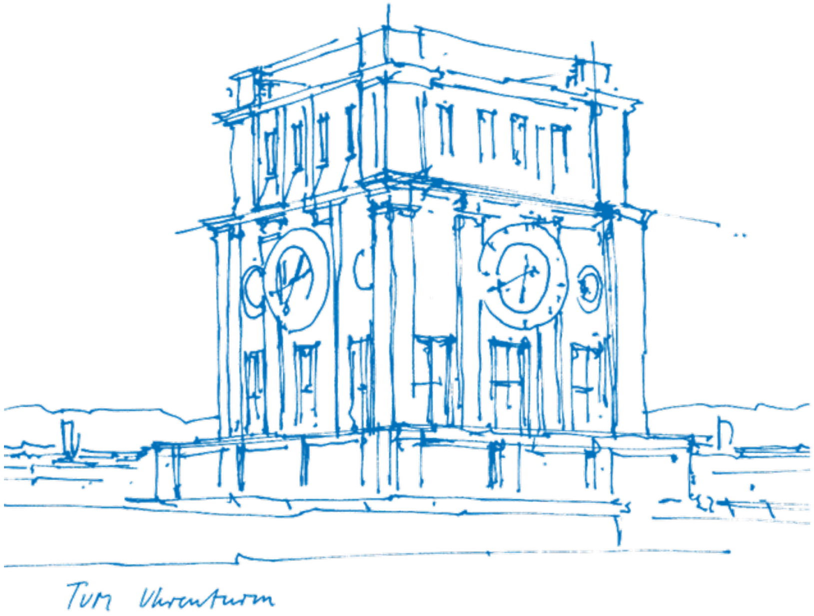
Deep Learning Methods for Reynolds-Averaged Navier-Stokes Simulations of Airfoil Flows



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Chair of Computer Graphics and Visualization
Munich, 11. May 2020

Introduction

TODO

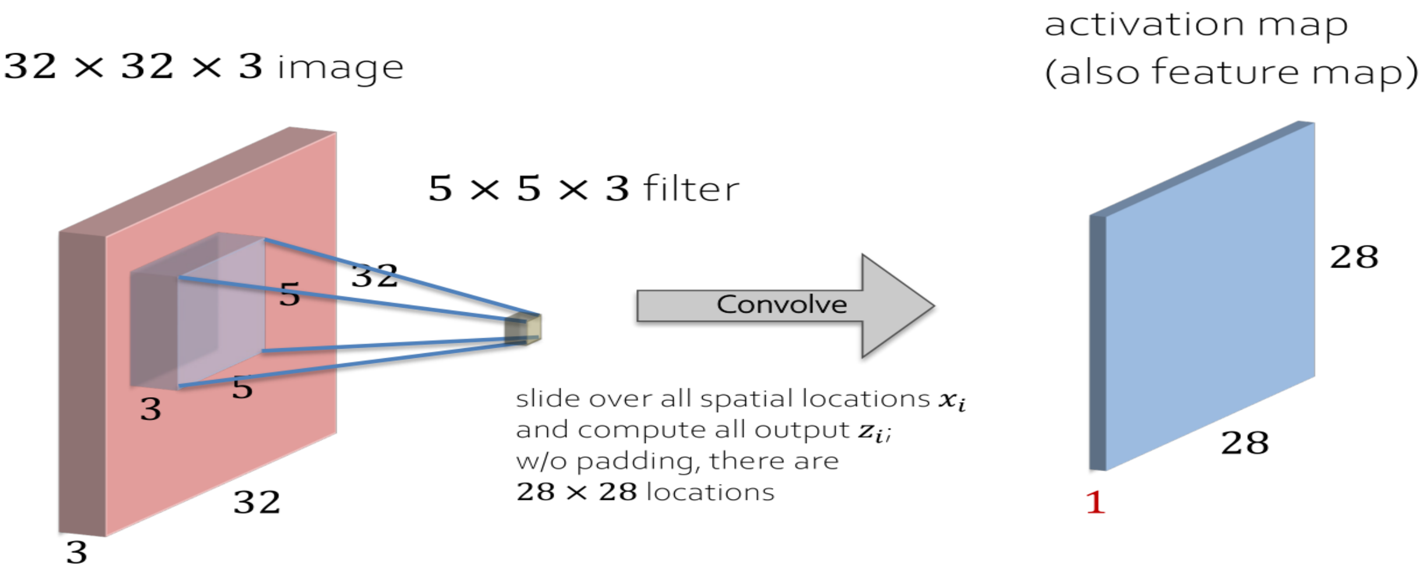
Background – RANS

TODO

Background – RANS

TODO

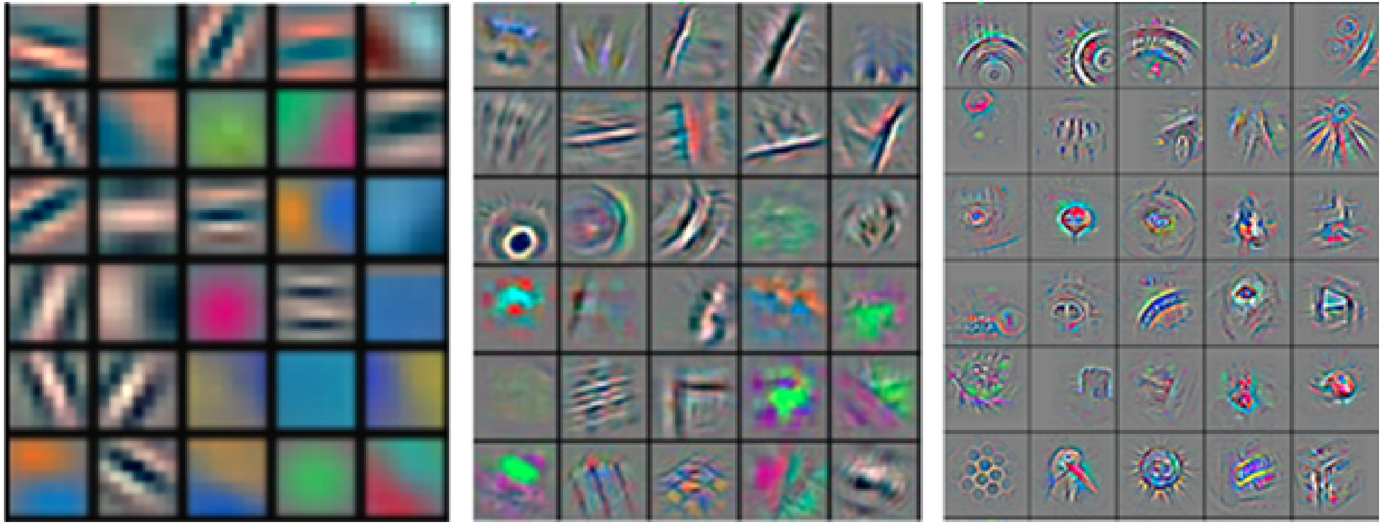
Background – Convolutions



Taken from I2DL WS19/20 (TUM)

Background – Convolutions

Low-Level Features, Mid-Level Features, High-Level Features: each filter captures different characteristics



Taken from `https://arxiv.org/pdf/1311.2901.pdf`

Data Generation

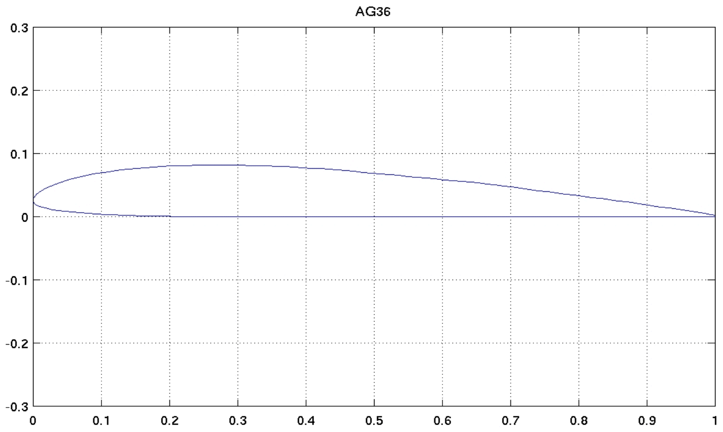
Airfoil shapes are provided by the UIUC database

Reynolds number: $[0.5, 5] \cdot 10^6$ (highly turbulent)

Angle of attack: $[-22.5, 22.5]$

Ground truth generated with OpenFOAM
(pressure, x velocity, y velocity)

Training data resolution: $3 \times 128 \times 128$



Pre-processing – Data

Input channels

1. Bit mask representing airfoil shape
2. x velocity component
3. y velocity component

Reynolds number encoded as differently scaled freestream velocity vectors wrt. their magnitude

Target channels

1. Pressure field
2. x velocity field
3. y velocity field

Data from the RANS solution

Pre-processing – Normalization

Motivation: Flatten space of solutions, accelerate learning by simplifing the learning task for the NN

Normaliztion of target channels by division with freestream magnitude (vector norm, default: L2):
This makes pressure and velocity dimensionless

$\tilde{v_o} = \frac{v_o}{\|v_i\|}, \quad \tilde{p_o} = \frac{p_o}{\|v_i\|^2}$ – important to remove quadratic scaling of pressure

For a better understanding:
Pressure: $[p]_{SI} = 1\,Pa = 1\,\frac{kg}{m \cdot s^2}$
Density: $[\rho]_{SI} = 1\,\frac{kg}{m^3}$ – constant in incompressible flow
Velocity: $[v]_{SI} = \frac{m}{s}$

Pre-processing – Offset removal & value clamping

Motivation: eliminate ill-posed learning goal & improve numerical precision

Spatially move pressure distribution into the origin

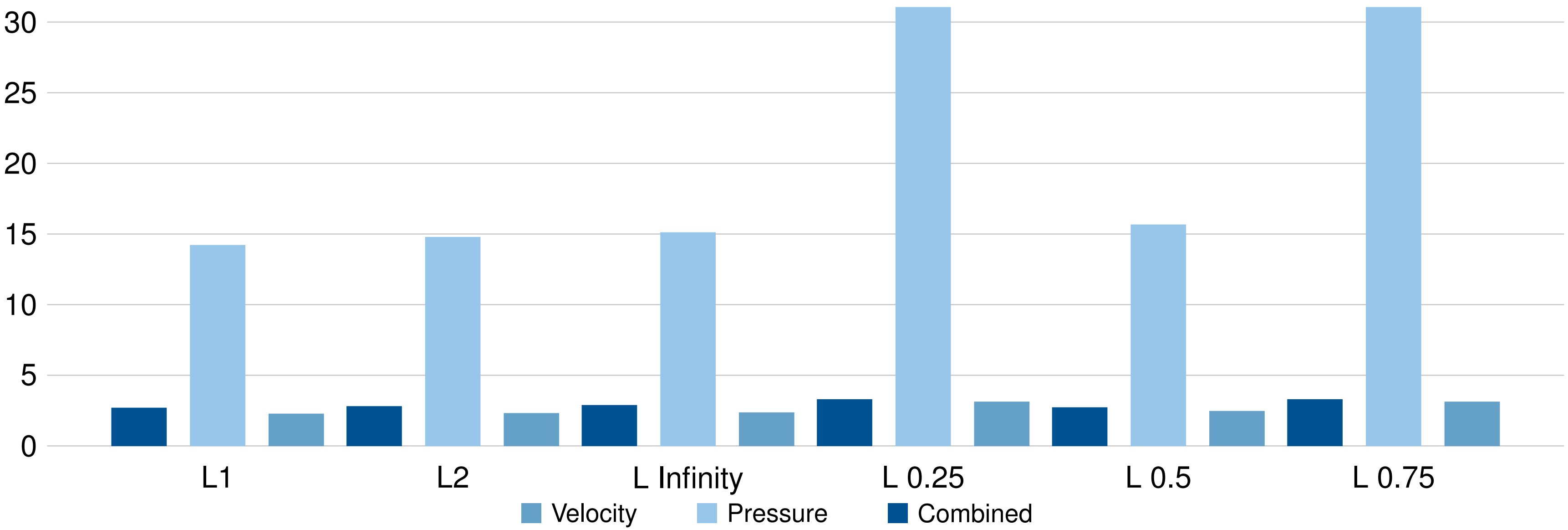
$\hat{p}_o = \tilde{p}_o - p_{mean}$

Clamp both input and target channels into $[-1, 1]$ range by diving by the maximum absolute value

Pre-processing – Evaluation

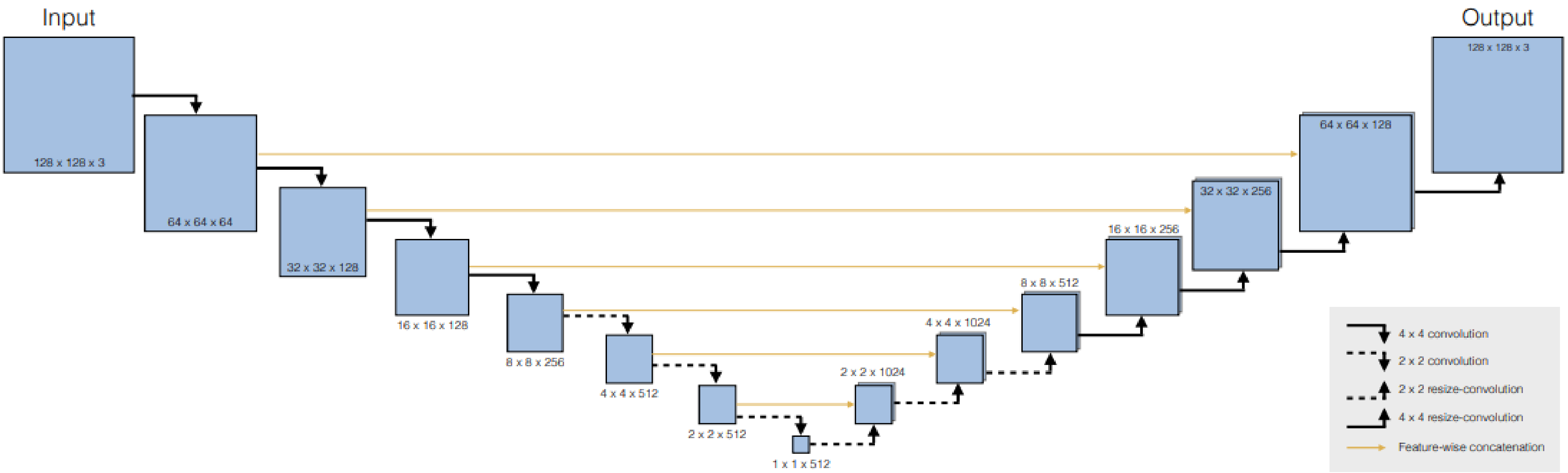
Vector norms used in pre-processing comparision wrt. error, default: L2 (in %)

L1 normalization achieves the best error rates (p, vel, combined: **14.19**%, **2.251**%, **2.646**% – L2: 14.76%, 2.291%, 2.780%)



Architecture

U-Net derivative proposed in the paper:



Taken from `https://arxiv.org/pdf/1810.08217.pdf`

Architecture – Convolutional blocks

Encoder

1. Activation – Leaky ReLu (0.2)
2. Convolution – Width down, Depth up
3. Batch normalization
4. Dropout (1%)

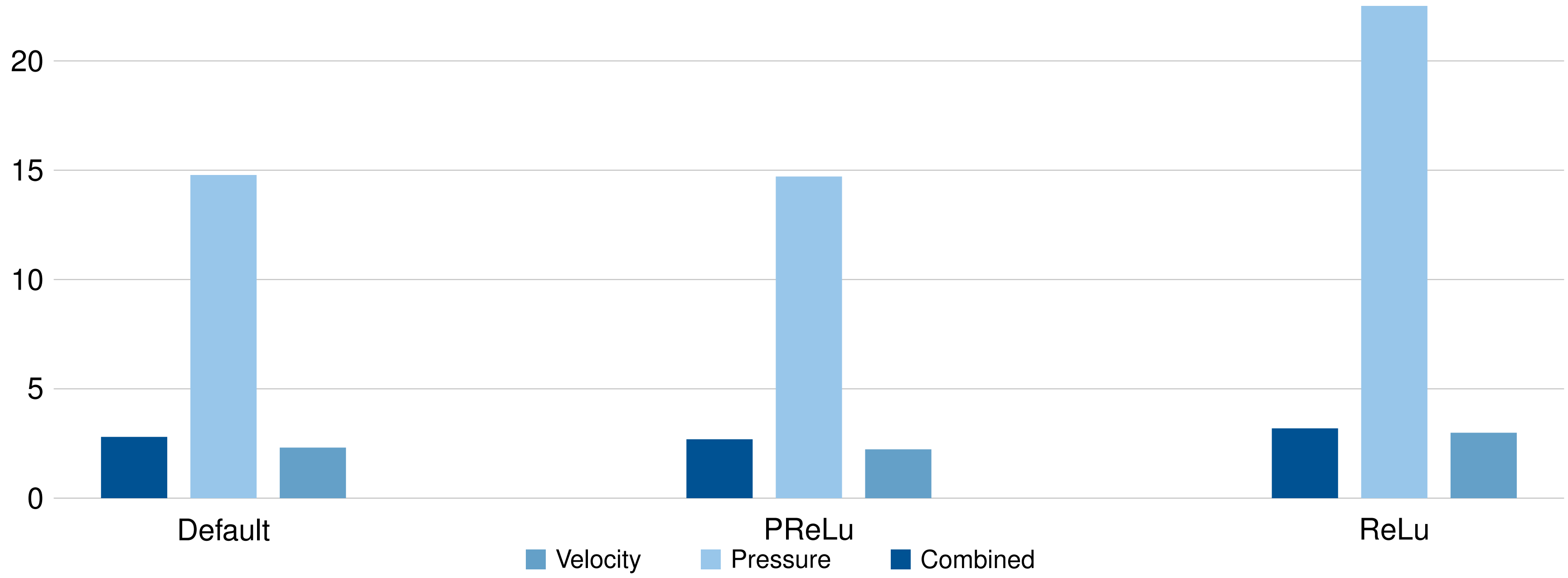
Decoder

1. Activation – ReLu
2. Upsampling – linear (2.0)
3. Convolution – Width up, Depth down
4. Batch normalization
5. Dropout (1%)

Architecture – Evaluation

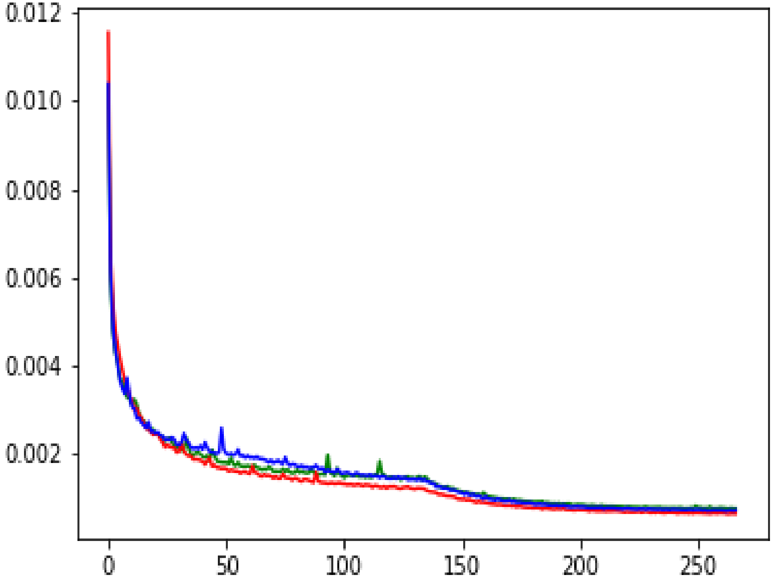
Error percentage of different activation functions after 160k iterations (266 epochs).

PReLu achieves the best error rates (p, vel, combined: **14.69**%, **2.216**%, **2.676**% – Default: 14.76%, 2.296%, 2.787%)

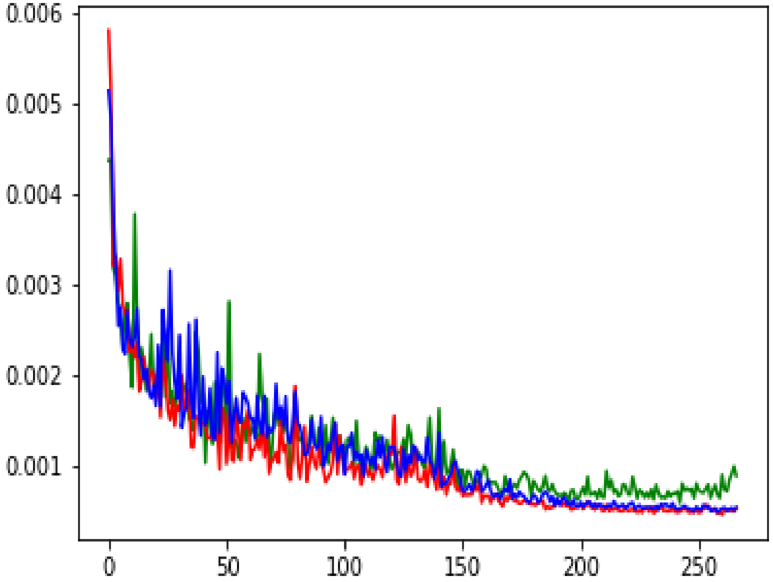


Architecture – Evaluation

Training loss



Validation loss

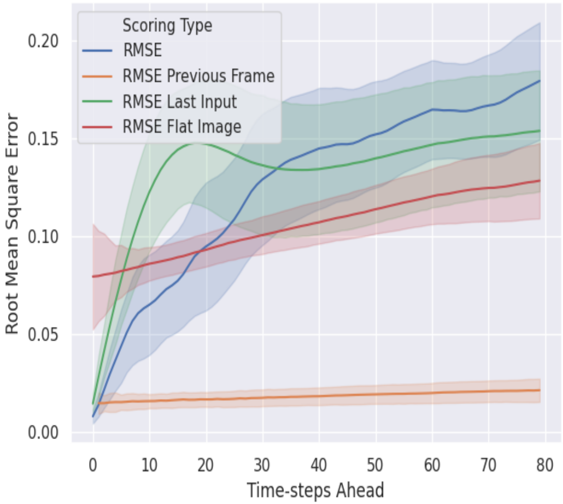


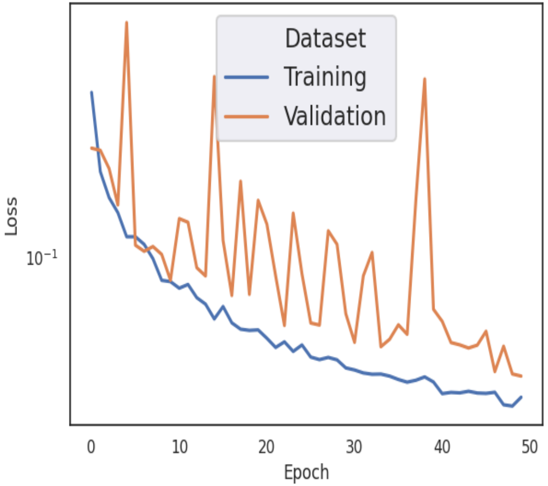
Transfer

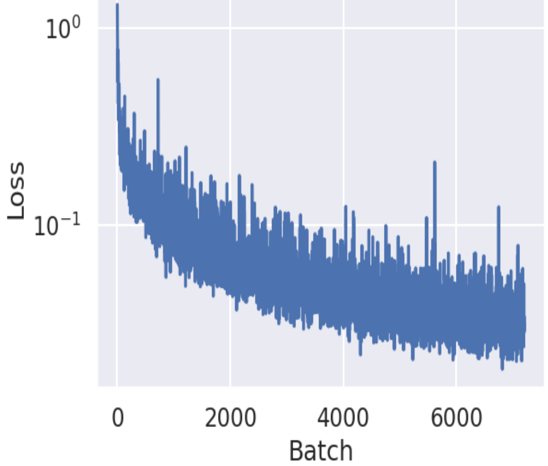
TODO

Transfer

RMSE with variance, validation loss and batch loss on Bigger Tub environment:





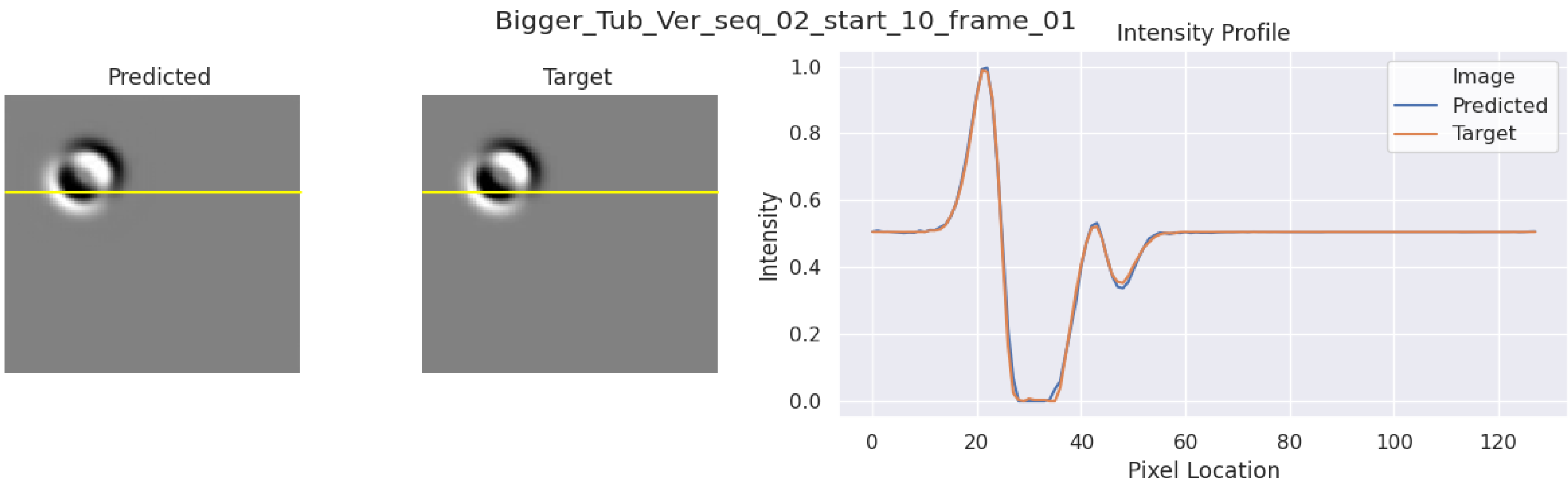


All plots in Transfer were made with `https://github.com/stathius/wave_propagation`

Transfer

Wave propagation prediction

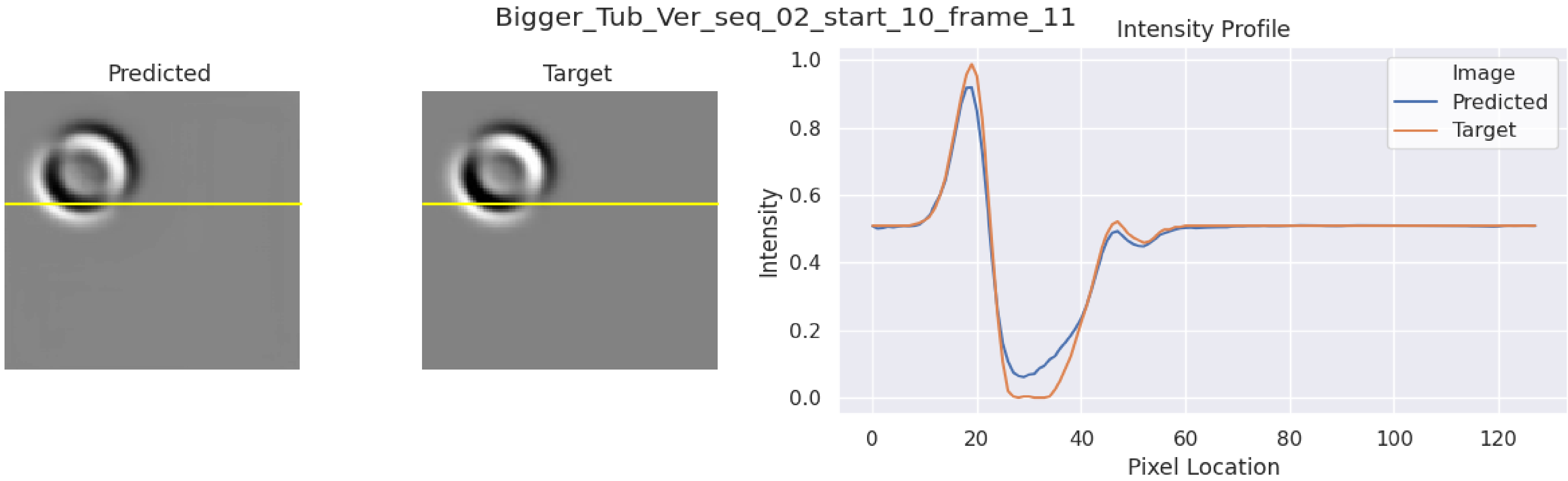
Intensity profile on scanline – Frame 1



Transfer

Wave propagation prediction

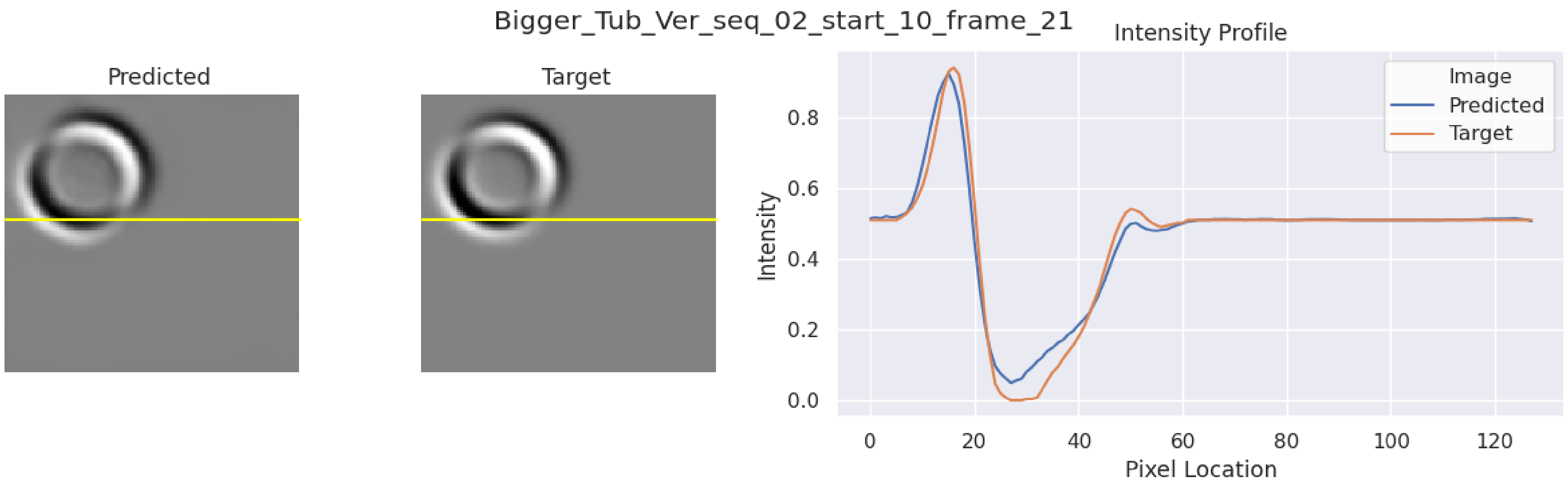
Intensity profile on scanline – Frame 11



Transfer

Wave propagation prediction

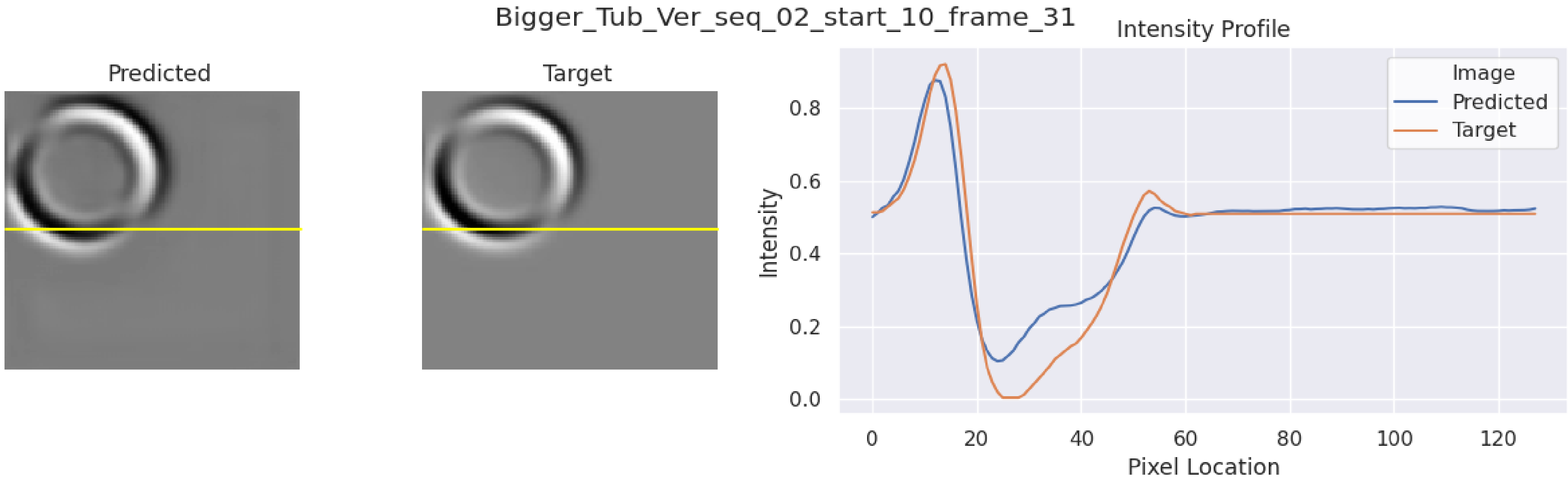
Intensity profile on scanline – Frame 21



Transfer

Wave propagation prediction

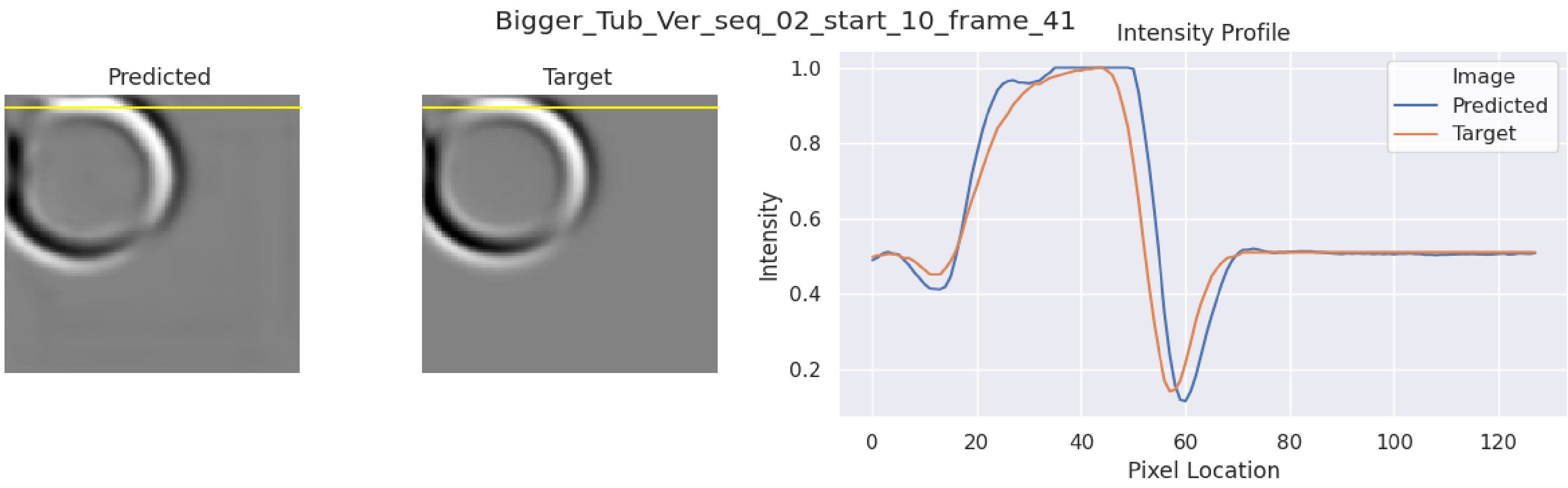
Intensity profile on scanline – Frame 31



Transfer

Wave propagation prediction

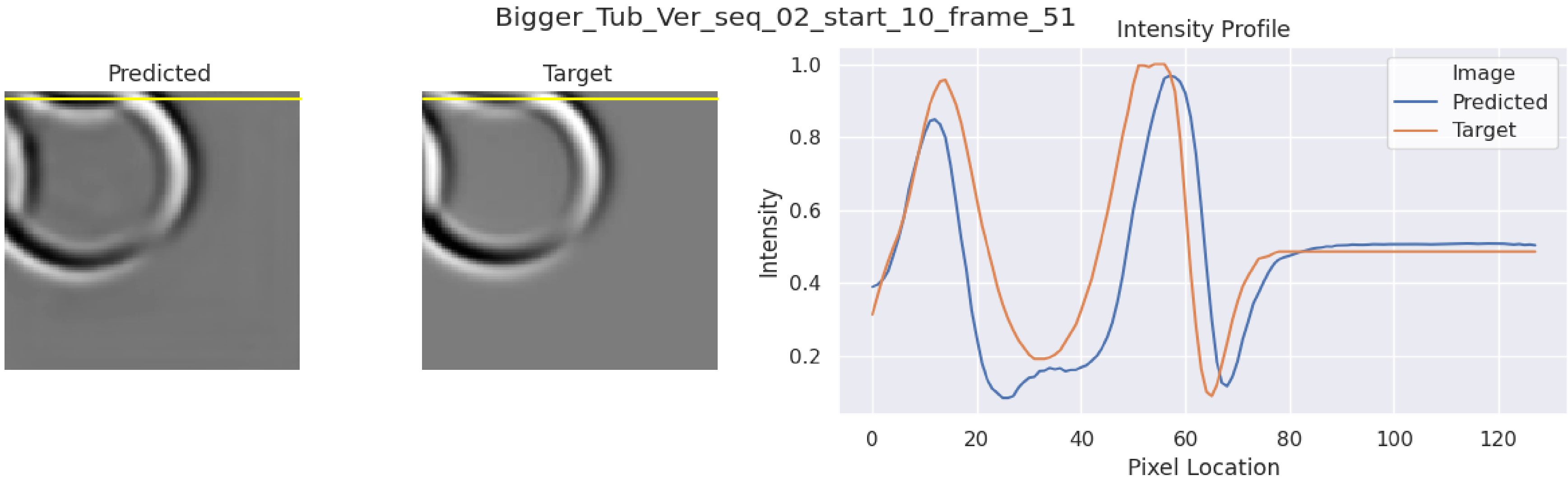
Intensity profile on scanline – Frame 41



Transfer

Wave propagation prediction

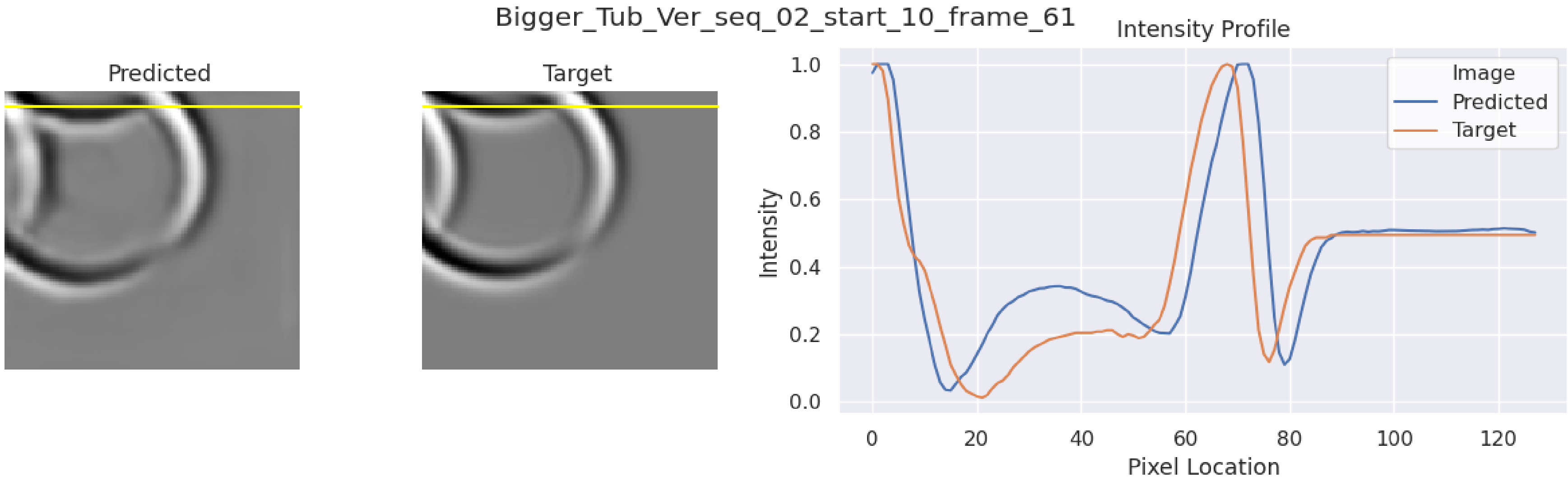
Intensity profile on scanline – Frame 51



Transfer

Wave propagation prediction

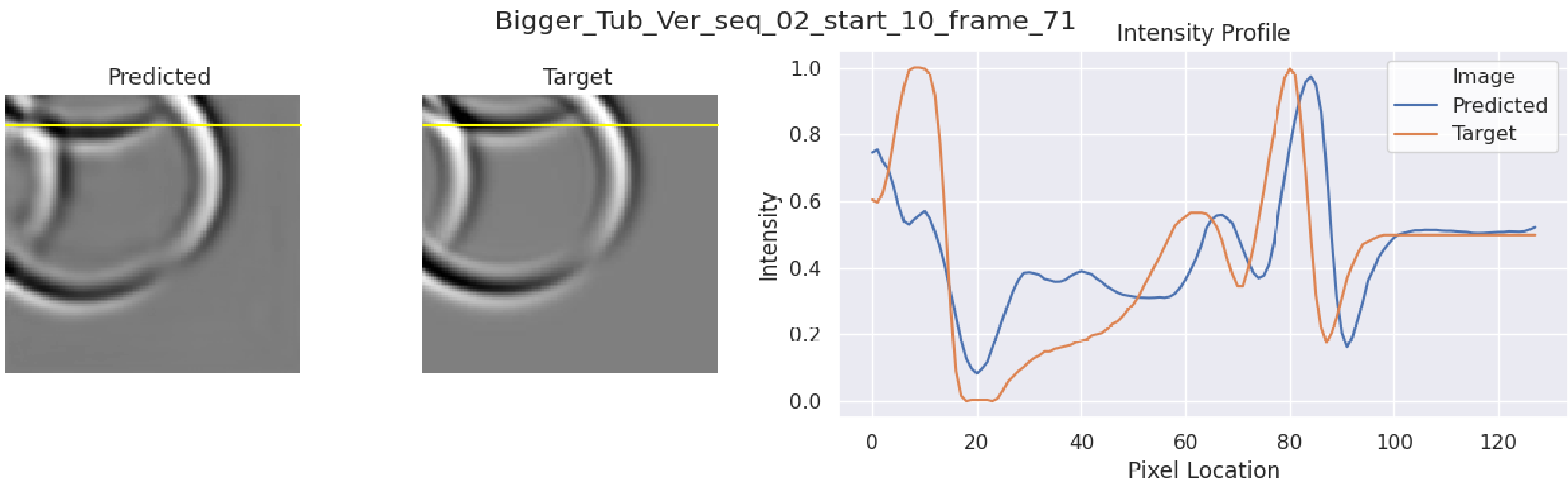
Intensity profile on scanline – Frame 61



Transfer

Wave propagation prediction

Intensity profile on scanline – Frame 71

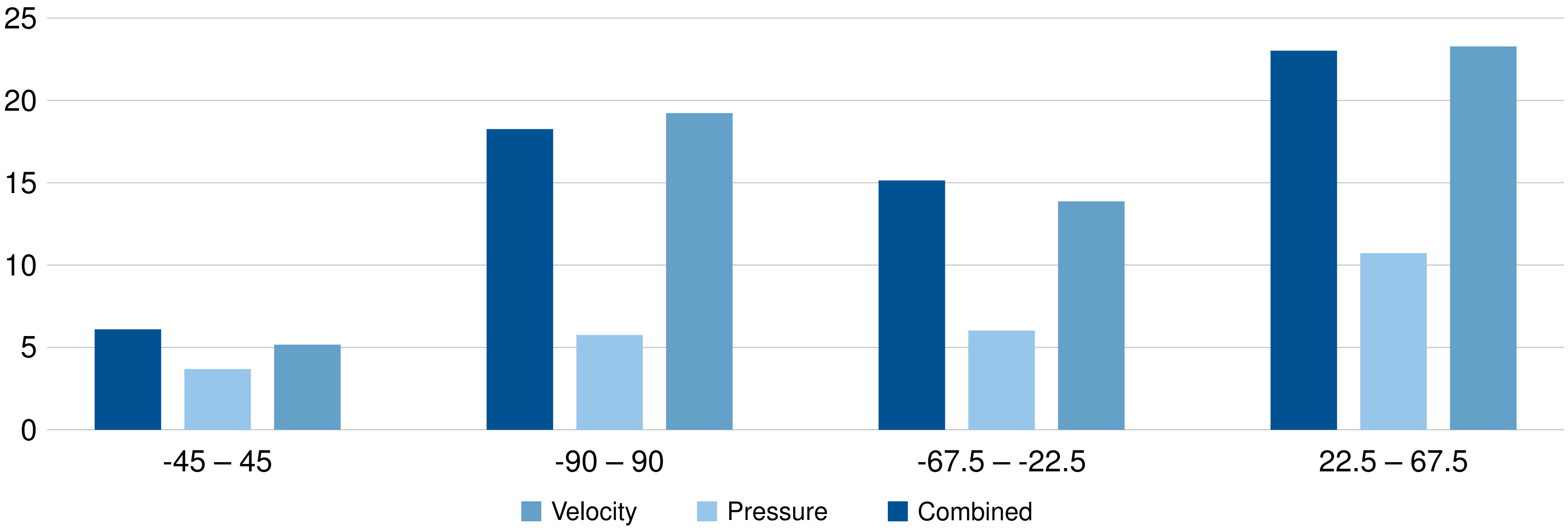


Generalization

TODO

Generalization

Error percentage of different angle of attack intervals wrt. ground truth $[-22.5, 22.5]$



Discussion

TODO

Discussion

Positiv

Punkt 1

Punkt 2

Punkt 3

Punkt 4

Negativ

Punkt 1

Punkt 2

Punkt 3

Punkt 4

Summary

TODO

Backup slides

TODO