Lab Notebook

Pupil Reconstruction

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Contents

1   Amplitude and Phase Reconstruction

16 February 2024

- Create new github branch: `AmpPhaseReconstructionRetraining`

- Download the following the files from Morgana:

  - `superK_slmcube_20230625_complsines-01sp_07`
  - `slmcube_20230625_complsines-01sp_07_PSFWFs_file00`
  - `slmcube_20230625_complsines-01sp_07_PSFWFs_file01`
  - `slmcube_20230625_complsines-01sp_07_PSFWFs_file02`
  - `slmcube_20230625_complsines-01sp_07_PSFWFs_file03`
  - `slmcube_20230625_complsines-01sp_07_PSFWFs_file04`
  - `slmcube_20230625_complsines-01sp_07_PSFWFs_file05`
  - `slmcube_20230625_complsines-01sp_07_PSFWFs_file06`
  - `slmcube_20230625_complsines-01sp_07_PSFWFs_file07`
  - `slmcube_20230625_complsines-01sp_07_PSFWFs_file08`
  - `slmcube_20230625_complsines-01sp_07_PSFWFs_file09`

- Data processing for Fully Convolutional NN training

- One fast experiment for each file: very good results, around 0.05 validation mse

19 February 2024

- Remove normalization from amplitude and phase for the fully connected experiments

---

EXPERIMENT NewFC10000-Processed 2

HYPERPARAMETERS:

```
*ARCHITECTURE HYPERPARAMETERS:

  -Fully Connected

  -Input shape: 1320

  -Output shape: (2, 96, 96)

  -Hidden layers: [2000, 2000, 2000, 2000]

  -Regularizer: None

  -Hidden Layers Activation: relu

  -Output Layer Activation: linear

  -Batch Normalization: False

  -Dropout: False, 0.2


*COMPILATION HYPERPARAMETERS:

  -Optimizer: ADAM lr=0.001, beta_1=0.9, beta_2=0.999

  -Loss Function: MSE

  -Metric: MSE
```

```
*TRAINING HYPERPARAMETERS:

  -Epochs: 200

  -Batch size: 64

  -Callbacks:

    -ReduceLROnPlateau: MSE 10 x0.1

    -Early Stop: MSE 25
```

VISUALIZATION:

```
*RESULTS:

      -Train MSE: 0.035130929201841354

      -Validation MSE: 0.0786573588848114
```
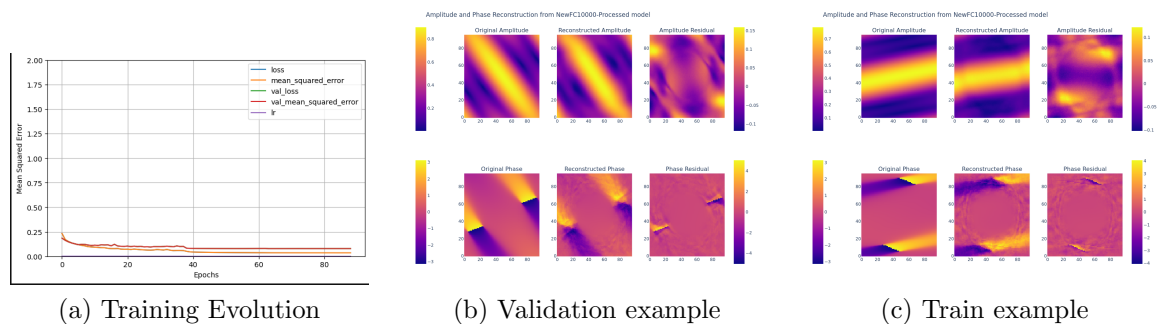

(a) Training Evolution   (b) Validation example   (c) Train example

Figure 1: Results of training the model NewFC10000-Processed 2

EXPERIMENT NewFC30000-Processed-1

HYPERPARAMETERS:

```
*ARCHITECTURE HYPERPARAMETERS:

  -Fully Connected

  -Input shape: 1320

  -Output shape: (2, 96, 96)

  -Hidden layers: [2000, 2000, 2000, 2000]

  -Regularizer: None

  -Hidden Layers Activation: relu

  -Output Layer Activation: linear

  -Batch Normalization: False

  -Dropout: False, 0.2


*COMPILATION HYPERPARAMETERS:

  -Optimizer: ADAM lr=0.001, beta_1=0.9, beta_2=0.999

  -Loss Function: MSE

  -Metric: MSE


*TRAINING HYPERPARAMETERS:

  -Epochs: 200

  -Batch size: 64

  -Callbacks:

    -ReduceLROnPlateau: MSE 10 x0.1

    -Early Stop: MSE 25
```

VISUALIZATION:

```
*RESULTS:
      -Train MSE: 0.0357743538916111
      -Validation MSE: 0.057852283120155334
```


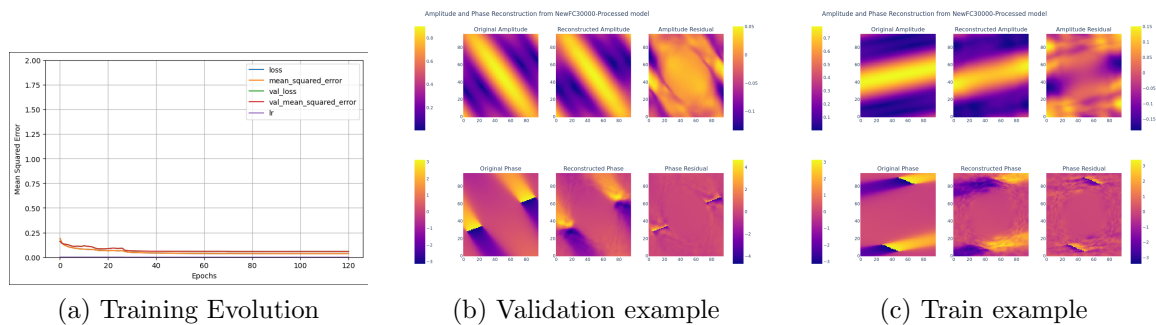| (a) Training Evolution | (b) Validation example | (c) Train example |

Figure 2: Results of training the model NewFC30000-Processed-1

EXPERIMENT NewFC80000-Processed-1

HYPERPARAMETERS:

```
*ARCHITECTURE HYPERPARAMETERS:
  -Fully Connected
  -Input shape: 1320
  -Output shape: (2, 96, 96)
  -Hidden layers: [2000, 2000, 2000, 2000]
  -Regularizer: None
  -Hidden Layers Activation: relu
```

```
  -Output Layer Activation: linear

  -Batch Normalization: False

  -Dropout: False, 0.2


*COMPILATION HYPERPARAMETERS:

  -Optimizer: ADAM lr=0.001, beta_1=0.9, beta_2=0.999

  -Loss Function: MSE

  -Metric: MSE


*TRAINING HYPERPARAMETERS:

  -Epochs: 200

  -Batch size: 64

  -Callbacks:

    -ReduceLROnPlateau: MSE 10 x0.1

    -Early Stop: MSE 25
```

VISUALIZATION:

```
*RESULTS:

    -Train MSE: 0.0330180414O210152

    -Validation MSE: 0.04487497732043266
```

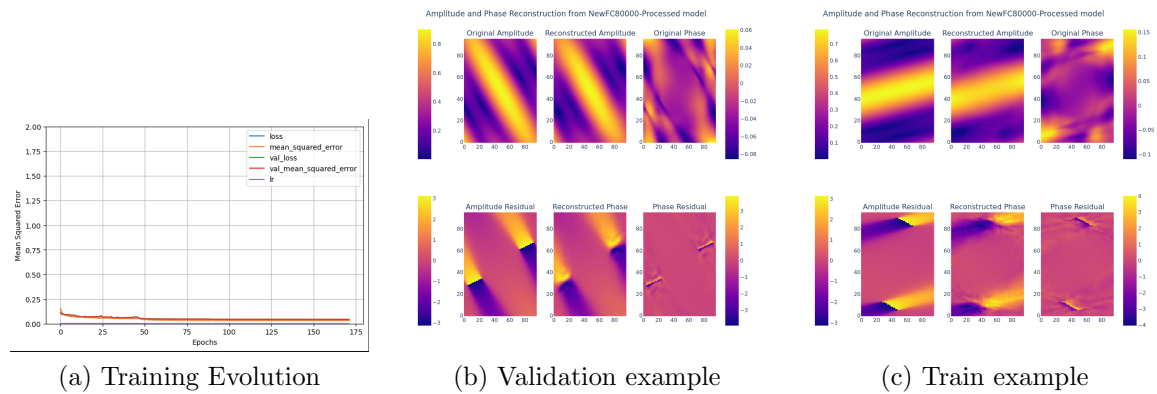(a) Training Evolution   (b) Validation example   (c) Train example

Figure 3: Results of training the model NewFC80000-Processed-1

- Normalize and split fluxes in train, validation and test files

- Stack amplitude and phase arrays and save in train, validation and test files

EXPERIMENT NewConv10000-1

HYPERPARAMETERS:

```
*ARCHITECTURE HYPERPARAMETERS:
  -Convolutional
  -Input shape: (55, 24, 1)
  -Output shape: (96, 96, 2)
  -Convolutional Layers: [128, 256, 512]
  -Convolutonal Kernels: [(3, 3), (3, 3), (3, 3)]
```

```
   -Fully Connected Hidden layers: [4096, 2048, 2048, 1024, 1024, 102
   -Regularizer: None
   -Convolutional Activation: relu
   -Hidden Layers Activation: relu
   -Output Layer Activation: linear
   -Batch Normalization: True


 *COMPILATION HYPERPARAMETERS:
   -Optimizer: ADAM lr=0.001, beta_1=0.9, beta_2=0.999
   -Loss Function: MSE
   -Metric: MSE


 * TRAINING HYPERPARAMETERS:
   -Epochs: 200
   -Batch size: 32
   -Callbacks:
     -ReduceLROnPlateau: MSE 15 x0.1
     -Early Stop: MSE 50
```

VISUALIZATION:

```
 *RESULTS:
      -Train MSE: 0.031087761744856834
      -Validation MSE: 0.09376049041748047
```
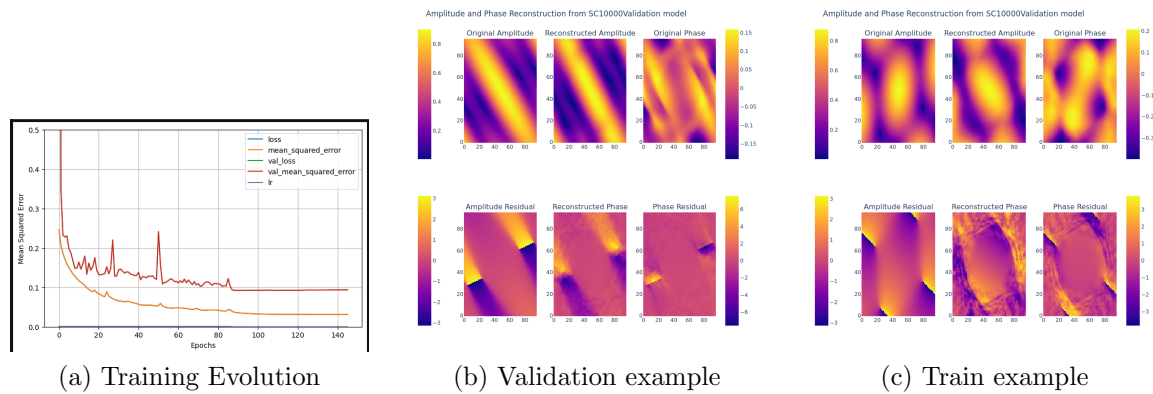
(a) Training Evolution   (b) Validation example   (c) Train example

Figure 4: Results of training the model NewConv10000-1

20 February 2024

EXPERIMENT NewConv30000-1

HYPERPARAMETERS:

```
*ARCHITECTURE HYPERPARAMETERS:
  -Convolutional
  -Input shape: (55, 24, 1)
  -Output shape: (96, 96, 2)
  -Convolutional Layers: [128, 256, 512]
  -Convolutonal Kernels: [(3, 3), (3, 3), (3, 3)]
```

```
  -Fully Connected Hidden layers: [4096, 2048, 2048, 1024, 1024, 102

  -Regularizer: None

  -Convolutional Activation: relu

  -Hidden Layers Activation: relu

  -Output Layer Activation: linear

  -Batch Normalization: True


*COMPILATION HYPERPARAMETERS:

  -Optimizer: ADAM lr=0.001, beta_1=0.9, beta_2=0.999

  -Loss Function: MSE

  -Metric: MSE


* TRAINING HYPERPARAMETERS:

  -Epochs: 200

  -Batch size: 32

  -Callbacks:

    -ReduceLROnPlateau: MSE 15 x0.1

    -Early Stop: MSE 50
```

VISUALIZATION:

```
*RESULTS:

     -Train MSE: 0.03819489851593971

     -Validation MSE: 0.06443119794130325
```

(a) Training Evolution   (b) Validation example   (c) Train example
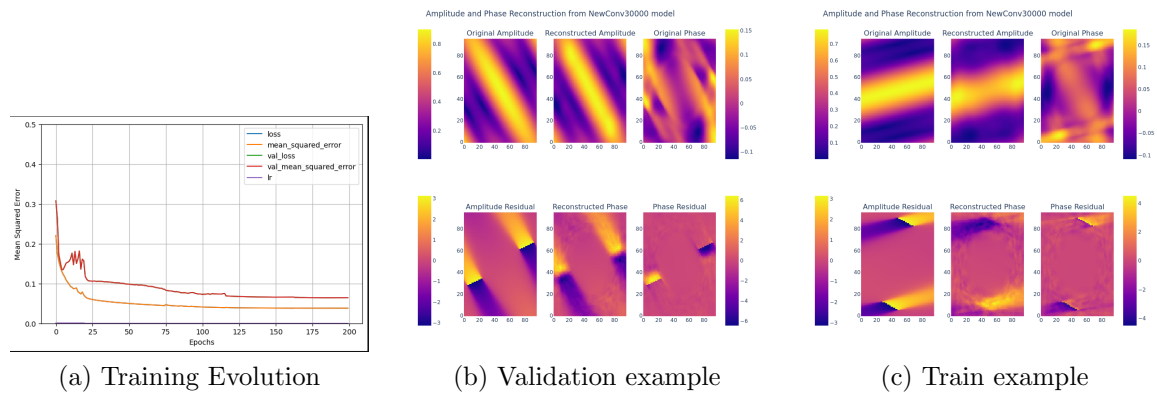
Figure 5: Results of training the model NewConv30000-1

EXPERIMENT NewConv30000-1

HYPERPARAMETERS:

```
*ARCHITECTURE HYPERPARAMETERS:
  -Convolutional
  -Input shape: (55, 24, 1)
  -Output shape: (96, 96, 2)
  -Convolutional Layers: [128, 256, 512]
  -Convolutonal Kernels: [(3, 3), (3, 3), (3, 3)]
  -Fully Connected Hidden layers: [4096, 2048, 2048, 1024, 1024, 102
  -Regularizer: None
  -Convolutional Activation: relu
  -Hidden Layers Activation: relu
```

```
   -Output Layer Activation: linear

   -Batch Normalization: True


 *COMPILATION HYPERPARAMETERS:

   -Optimizer: ADAM lr=0.001, beta_1=0.9, beta_2=0.999

   -Loss Function: MSE

   -Metric: MSE


 *  TRAINING HYPERPARAMETERS:

   -Epochs: 200

   -Batch size: 32

   -Callbacks:

     -ReduceLROnPlateau: MSE 15 x0.1

     -Early Stop: MSE 50
```

VISUALIZATION:

```
 *RESULTS:

     -Train MSE: 0.030630357563495636

     -Validation MSE: 0.08355200290679932
```
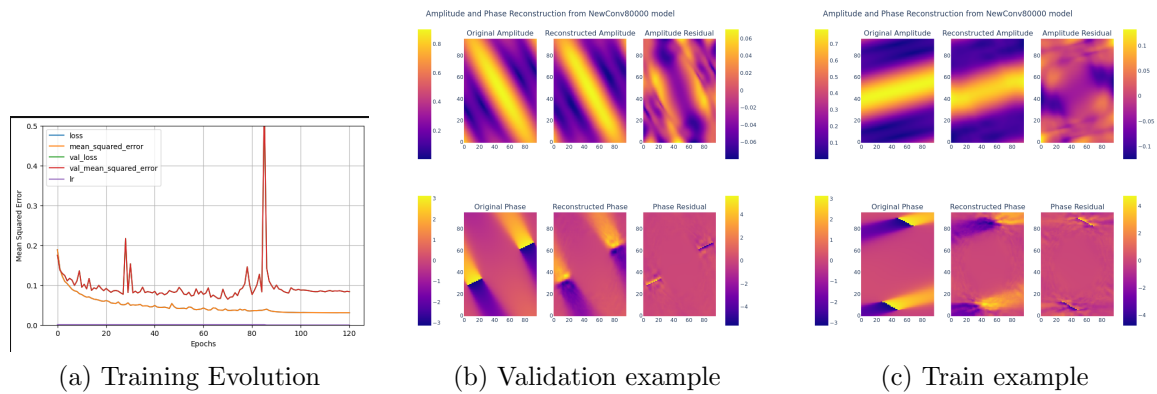
(a) Training Evolution   (b) Validation example   (c) Train example

Figure 6: Results of training the model NewConv80000-1

- Normalize flux data and add padding for flux autoencoder

- Stack amplitude and phase and add padding for encoder+convolutional model

EXPERIMENT NewFluxAutoencoder10000-1

HYPERPARAMETERS:

```
*ARCHITECTURE HYPERPARAMETERS:

  -Autoencoder

  -Input shape: (56, 24, 1)

  -Convolutional Layers: [512, 128, 64, 8]

    (Inverse in the decoder)

  -Convolutonal Kernels: [(3, 3), (3, 3), (3, 3), (3, 3)]
```

```
     (Inverse in the decoder)
  -Convolutional Activation: relu
  -Output Layer Activation: linear
  -Padding: same
  -Use Batch Normalization: True


*COMPILATION HYPERPARAMETERS:
  -Optimizer: ADAM lr=0.001, beta_1=0.9, beta_2=0.999
  -Loss Function: MSE
  -Metric: MSE


*TRAINING HYPERPARAMETERS:
  -Epochs: 75
  -Batch size: 32
  -Callbacks:
    -ReduceLROnPlateau: MSE 8 x0.1
    -Early Stop: MSE 15
```

VISUALIZATION:

```
*RESULTS:
     -Train MSE: 0.0018673702143132687
     -Validation MSE: 0.005482238717377186
```

(a) Training Evolution   (b) Validation example   (c) Train example
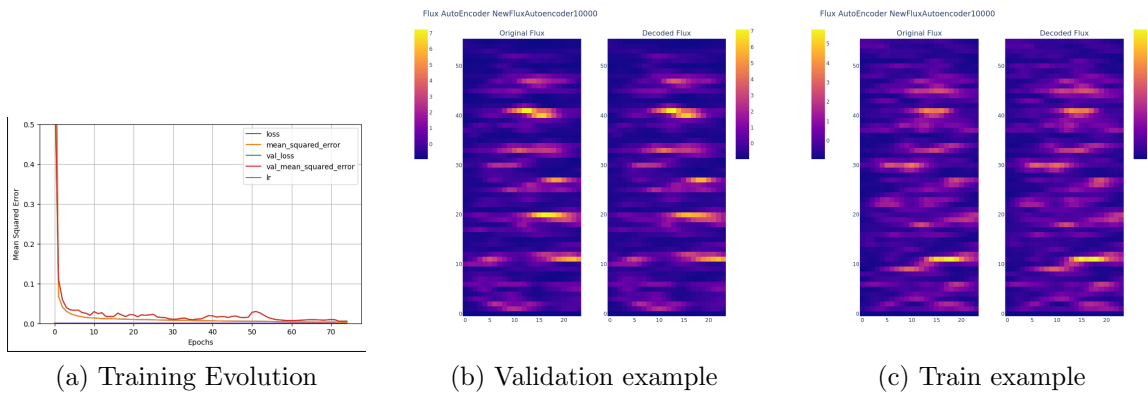
Figure 7: Results of training the model NewFluxAutoencoder10000-1

21 February 2024

EXPERIMENT NewFluxAutoencoder80000-1

HYPERPARAMETERS:

```
*ARCHITECTURE HYPERPARAMETERS:
  -Autoencoder
  -Input shape: (56, 24, 1)
  -Convolutional Layers: [512, 128, 64, 8]
    (Inverse in the decoder)
```

```
-Convolutonal Kernels: [(3, 3), (3, 3), (3, 3), (3, 3)]
  (Inverse in the decoder)
-Convolutional Activation: relu
-Output Layer Activation: linear
-Padding: same
-Use Batch Normalization: True


*COMPILATION HYPERPARAMETERS:
-Optimizer: ADAM lr=0.001, beta_1=0.9, beta_2=0.999
-Loss Function: MSE
-Metric: MSE


*TRAINING HYPERPARAMETERS:
-Epochs: 75
-Batch size: 32
-Callbacks:
  -ReduceLROnPlateau: MSE 8 x0.1
  -Early Stop: MSE 15
```

VISUALIZATION:

```
    -Train MSE: 0.024667566642165184
    -Validation MSE: 0.0158506091684103
```

(a) Training Evolution   (b) Validation example   (c) Train example
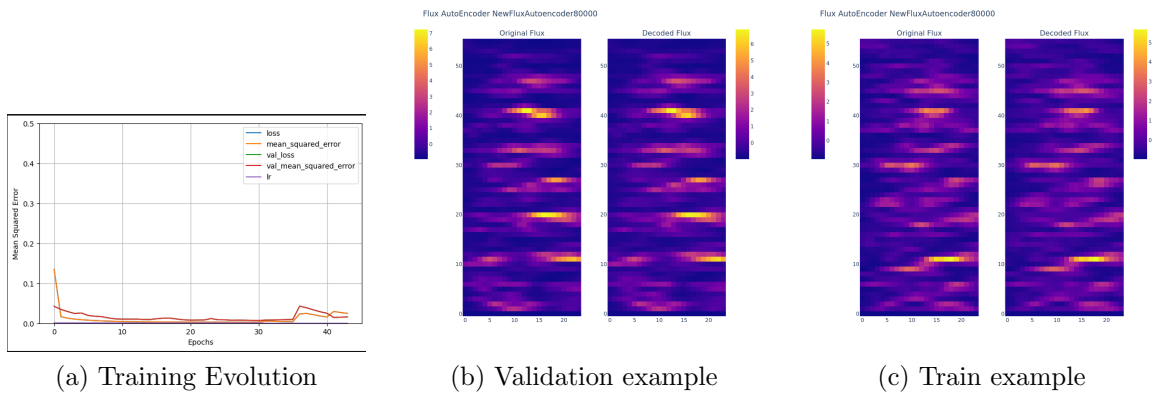
Figure 8: Results of training the model NewFluxAutoencoder10000-1

EXPERIMENT NewEncConv10000-1

HYPERPARAMETERS:

```
*ARCHITECTURE HYPERPARAMETERS:
  -Encoder + Convolutional
  -Convolutional Layers: [1024, 512, 256, 256]
  -Convolutonal Kernels: [(3, 3), (3, 3), (3, 3), (3, 3)]
  -Convolutional Activation: relu
  -Output Layer Activation: linear


*COMPILATION HYPERPARAMETERS:
  -Optimizer: ADAM lr=0.0001, beta_1=0.9, beta_2=0.999
  -Loss Function: MSE
```

```
    -Metric: MSE


*  TRAINING HYPERPARAMETERS:

   -Epochs: 100

   -Batch size: 32

   -Callbacks:

     -ReduceLROnPlateau: MSE 8 x0.1

     -Early Stop: MSE 15
```

VISUALIZATION:

```
 *RESULTS:

       -Train MSE: 0.011328332126140594

       -Validation MSE: 0.06024651601910591
```
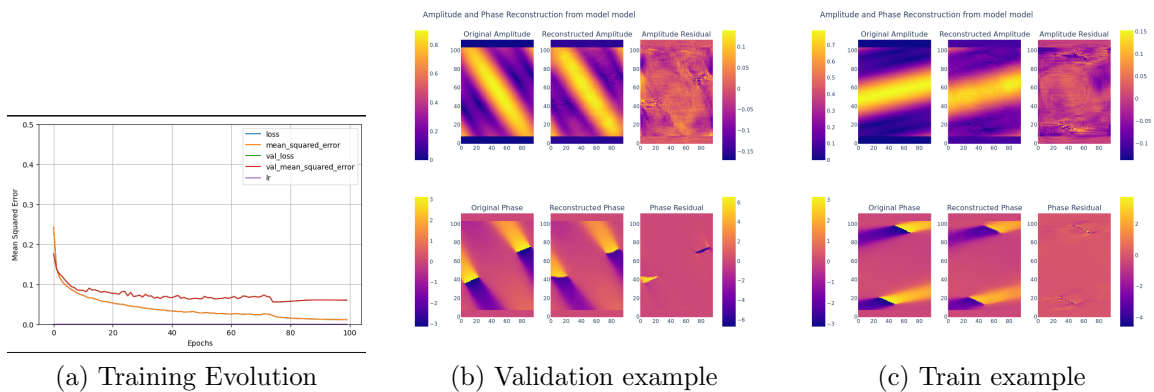

(a) Training Evolution   (b) Validation example   (c) Train example

Figure 9: Results of training the model NewEncConv10000-1

EXPERIMENT NewEncConv30000-1

HYPERPARAMETERS:

```
*ARCHITECTURE HYPERPARAMETERS:
  -Encoder + Convolutional
  -Convolutional Layers: [1024, 512, 256, 256]
  -Convolutonal Kernels: [(3, 3), (3, 3), (3, 3), (3, 3)]
  -Convolutional Activation: relu
  -Output Layer Activation: linear


*COMPILATION HYPERPARAMETERS:
  -Optimizer: ADAM lr=0.0001, beta_1=0.9, beta_2=0.999
  -Loss Function: MSE
  -Metric: MSE


* TRAINING HYPERPARAMETERS:
  -Epochs: 100
  -Batch size: 32
  -Callbacks:
    -ReduceLROnPlateau: MSE 8 x0.1
    -Early Stop: MSE 15
```

VISUALIZATION:

```
*RESULTS:
    -Train MSE: 0.016221819445490837
```
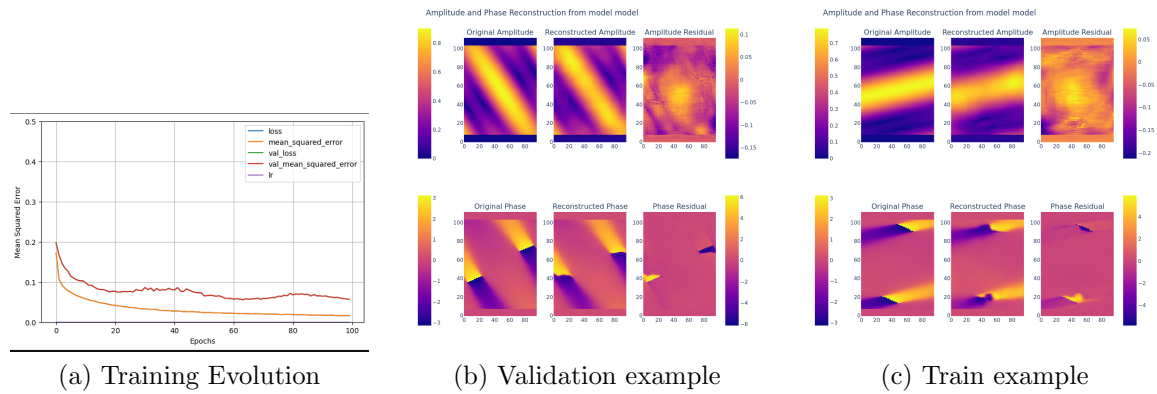
```
-Validation MSE: 0.05662507936358452
```


(a) Training Evolution   (b) Validation example   (c) Train example

Figure 10: Results of training the model NewEncConv30000-1

22 February 2024

EXPERIMENT NewEncConv80000-1

HYPERPARAMETERS:

```
*ARCHITECTURE HYPERPARAMETERS:

  -Encoder + Convolutional

  -Convolutional Layers: [1024, 512, 256, 256]
```

```
  -Convolutonal Kernels: [(3, 3), (3, 3), (3, 3), (3, 3)]

  -Convolutional Activation: relu

  -Output Layer Activation: linear


*COMPILATION HYPERPARAMETERS:

  -Optimizer: ADAM lr=0.0001, beta_1=0.9, beta_2=0.999

  -Loss Function: MSE

  -Metric: MSE


*  TRAINING HYPERPARAMETERS:

  -Epochs: 100

  -Batch size: 32

  -Callbacks:

    -ReduceLROnPlateau: MSE 8 x0.1

    -Early Stop: MSE 15
```

VISUALIZATION:

```
*RESULTS:

    -Train MSE: 0.0163

    -Validation MSE: 0.0369
```

(a) IGNORE THIS EVOLU-
TION FIGURE, TRAINING
FINISHED BEFORE STOR-
ING THE HISTORY, THIS IS
FROM THE PREVIOUS EX-
PERIMENT

(b) Validation example

(c) Train example
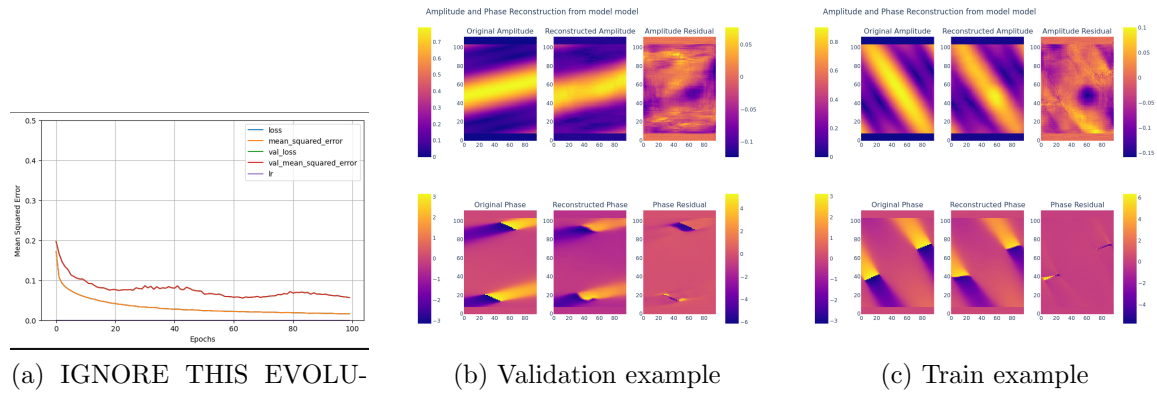
Figure 11: Results of training the model NewEncConv80000-1

2 PSF Reconstruction

20 February 2024

- Create custom dynamic dataloader for PL output flux and PSF complex field
  for PSF reconstruction

26 February 2024

- Create a dataloader to dynamically load flux and psf

- Normalize electric fields, real and imaginary parts independently

- Normalize PL output fluxes

- Train a fully connected nn with horrible results, train mse keeps stable at 1, will have to look at the data

27 February 2024

- Create plotting functions to show amplitude, phase and intensity from an electric field

- Normalize electric field, this time dividing the complex number matrix by a constant (50.000 in this case)

- Redo output flux calculation with the normalized electric fields through the transfer matrix of the 19 fibre PL

28 February 2024

EXPERIMENT PSF-FC-Reconstructor-1

HYPERPARAMETERS:

```
*ARCHITECTURE HYPERPARAMETERS:
  -Fully Connected
  -Input shape: 19
  -Output shape: 32768
  -Hidden layers: [2000, 2000, 2000, 2000]
  -Regularizer: None
  -Hidden Layers Activation: relu
  -Output Layer Activation: linear
  -Batch Normalization: False
  -Dropout: False, 0.2


*COMPILATION HYPERPARAMETERS:
  -Optimizer: ADAM lr=0.001, beta_1=0.9, beta_2=0.999
  -Loss Function: MSE
  -Metric: MSE


*TRAINING HYPERPARAMETERS:
  -Epochs: 200
```

```
-Batch size: 64
-Callbacks:
  -ReduceLROnPlateau: MSE 10 x0.1
  -Early Stop: MSE 25
```

VISUALIZATION:

```
    -Train MSE: 0.03701553866267204
    -Validation MSE: 0.03701810911297798
```
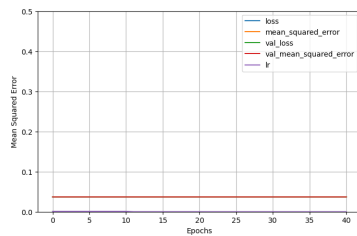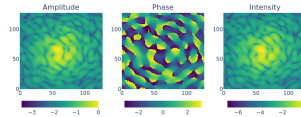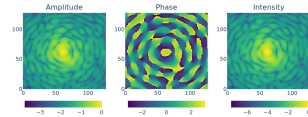

(a) Training Evolution   (b) Validation prediction   (c) Validation original

Figure 12: Results of training the model PSF-FC-Reconstructor-1

29 February 2024

- Create a function to plot amplitude and phase predictions and residuals from a complex field

- Create evaluation notebook

- Since in yesterdays experiment the model does not learn at all, I design two different experiments, to check if there is a problem with the network:

1. A model that sums the output flux of the PL

2. A model that sums the scalars of the complex numbers array containing the electric fields at the pupil.

EXPERIMENT Flux-Sum-1

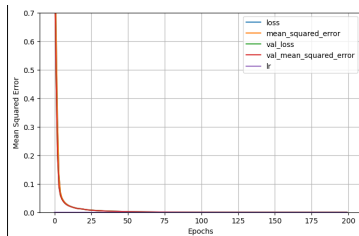This model performs a sum of all the output fluxes from the PL

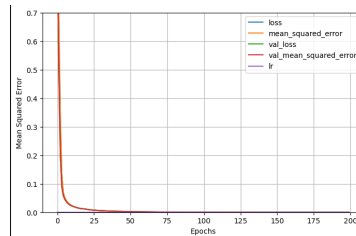HYPERPARAMETERS:

```
*ARCHITECTURE HYPERPARAMETERS:
  -Fully Connected
  -Input shape: 19
  -Output shape: 1
  -Hidden layers: [100, 100]
  -Regularizer: None
  -Hidden Layers Activation: relu
  -Output Layer Activation: linear
  -Batch Normalization: False
  -Dropout: False, 0.2


*COMPILATION HYPERPARAMETERS:
  -Optimizer: ADAM lr=0.0001, beta_1=0.9, beta_2=0.999
  -Loss Function: MSE
  -Metric: MSE
```
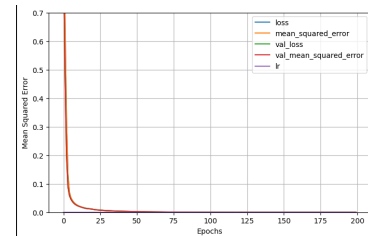
```
*TRAINING HYPERPARAMETERS:

  -Epochs: 200

  -Batch size: 64

  -Callbacks:

    -ReduceLROnPlateau: MSE 10 x0.1

    -Early Stop: MSE 25
```

VISUALIZATION:

```
*RESULTS:

    -Train MSE: 0.00018273142632097006

    -Validation MSE: 0.00018727070710156113
```


(a) Training Evolution   (b) Training Evolution   (c) Training Evolution

Figure 13: Results of training the model Flux-Sum-1

EXPERIMENT ElectricField-Sum-1

This model performs a sum of all the output fluxes from the PL

HYPERPARAMETERS:

```
*ARCHITECTURE HYPERPARAMETERS:

  -Fully Connected

  -Input shape: 32768

  -Output shape: 1

  -Hidden layers: [100, 100, 100]

  -Regularizer: None

  -Hidden Layers Activation: relu

  -Output Layer Activation: linear

  -Batch Normalization: False

  -Dropout: False, 0.2


*COMPILATION HYPERPARAMETERS:

  -Optimizer: ADAM lr=0.0001, beta_1=0.9, beta_2=0.999

  -Loss Function: MSE

  -Metric: MSE


*TRAINING HYPERPARAMETERS:

  -Epochs: 200

  -Batch size: 64

  -Callbacks:

    -ReduceLROnPlateau: MSE 10 x0.1

    -Early Stop: MSE 25
```
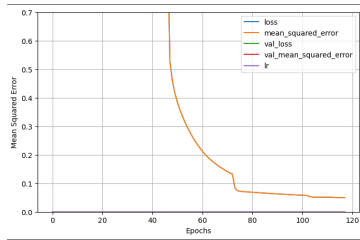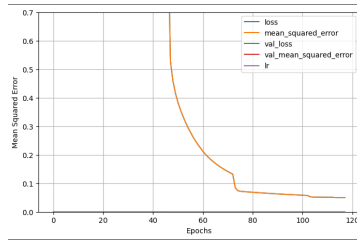
VISUALIZATION:

```
*RESULTS:

    -Train MSE: 0.050156451761722565

    -Validation MSE: 0.8189939856529236
```
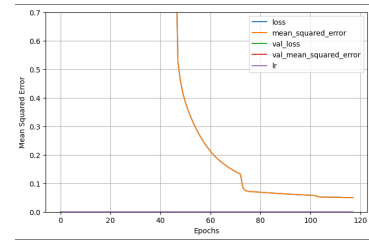

(a) Training Evolution   (b) Training Evolution   (c) Training Evolution

Figure 14: Results of training the model ElectricField-Sum-1

01 May 2024

- Today I decide to train a model with just one datapoint and see if is able to learn the PSF from one flux and one electric field

EXPERIMENT TestWith1DataPoint-1

HYPERPARAMETERS:

```
*ARCHITECTURE HYPERPARAMETERS:
```

```
-Fully Connected

-Input shape: 19

-Output shape: 32768

-Hidden layers: [1000, 1000, 1000, 1000]

-Regularizer: None

-Hidden Layers Activation: relu

-Output Layer Activation: linear

-Batch Normalization: False

-Dropout: False, 0.2


*COMPILATION HYPERPARAMETERS:

-Optimizer: ADAM lr=0.01, beta_1=0.9, beta_2=0.999

-Loss Function: MSE

-Metric: MSE


*TRAINING HYPERPARAMETERS:

-Epochs: 1000

-Batch size: 64

-Callbacks:

  -ReduceLROnPlateau: MSE 10 x0.1

  -Early Stop: MSE 25
```

VISUALIZATION:

```
-Train MSE: 0.03701553866267204

-Validation MSE: 0.03701810911297798
```

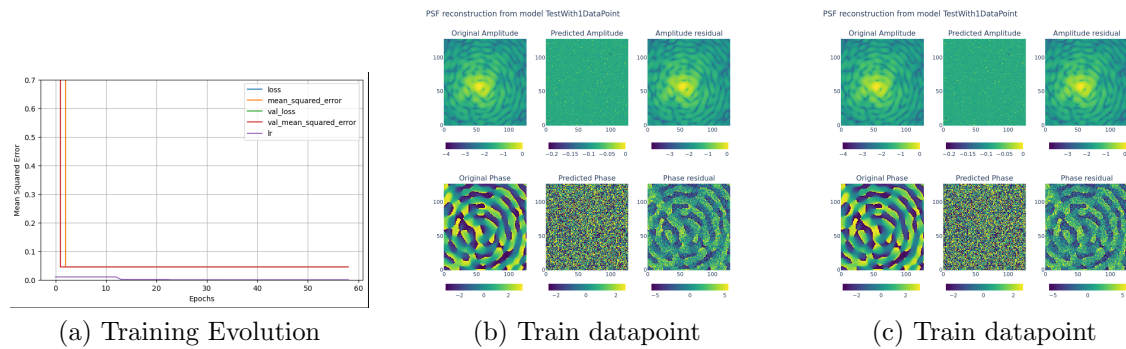(a) Training Evolution   (b) Train datapoint   (c) Train datapoint

Figure 15: Results of training the model TestWith1DataPoint-1

- Something is wrong, going try with a bigger NN, don't think this will change anything but I have to try just in case.

EXPERIMENT TestWith1DataPoint-2

HYPERPARAMETERS:

```
*ARCHITECTURE HYPERPARAMETERS:
  -Fully Connected
  -Input shape: 19
  -Output shape: 32768
  -Hidden layers: [128, 128, 128, 128, 256,
          256, 512, 2000, 4000]
  -Regularizer: None
```

```
  -Hidden Layers Activation: relu

  -Output Layer Activation: linear

  -Batch Normalization: False

  -Dropout: False, 0.2


*COMPILATION HYPERPARAMETERS:

  -Optimizer: ADAM lr=0.01, beta_1=0.9, beta_2=0.999

  -Loss Function: MSE

  -Metric: MSE


*TRAINING HYPERPARAMETERS:

  -Epochs: 1000

  -Batch size: 64

  -Callbacks:

    -ReduceLROnPlateau: MSE 10 x0.1

    -Early Stop: MSE 25
```

VISUALIZATION:

```
*RESULTS:

    -Train MSE: 0.04261719062924385

    -Validation MSE: 0.04261719062924385
```

(a) Training Evolution
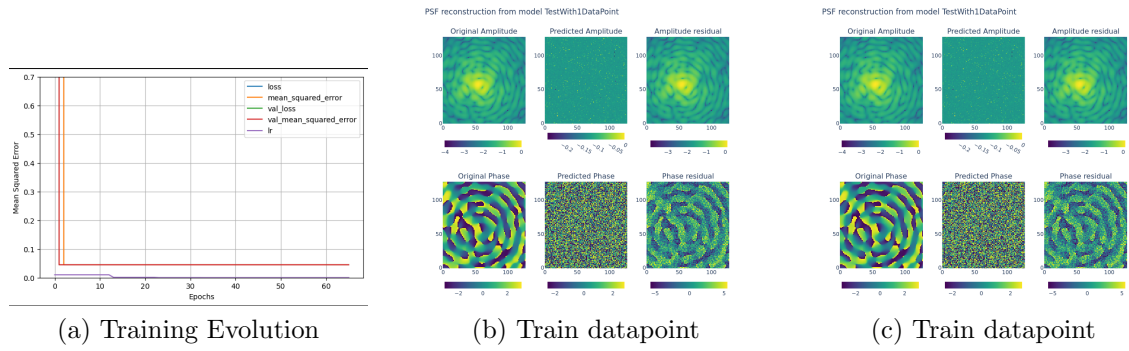
(b) Train datapoint

(c) Train datapoint

Figure 16: Results of training the model TestWith1DataPoint-1