Unsupervised image denoising

Import libraries

In [1]:

```
import torch
import torchvision
from torch.utils.data import Dataset
from os import listdir
from os.path import join
from torchvision.transforms import Compose, ToTensor, ToPILImage, Resize, Lambda
, Normalize, Grayscale
from torch.utils.data import DataLoader
from PIL import Image
import matplotlib.pyplot as plt
import numpy as np
import torch.nn as nn
import torch.nn.functional as F
import torch.optim as optim
from math import log10
from tqdm import tqdm
import os
```

Load data

In [2]:

```
directory_data  = './'
filename_data   = 'assignment_08_data.npz'
data            = np.load(os.path.join(directory_data, filename_data))

train       = data['x_train']
train_noise = data['x_train_noise']

test        = data['x_test']
test_noise  = data['x_test_noise']

num_train   = train.shape[0]
num_test    = test.shape[0]
```

In [3]:

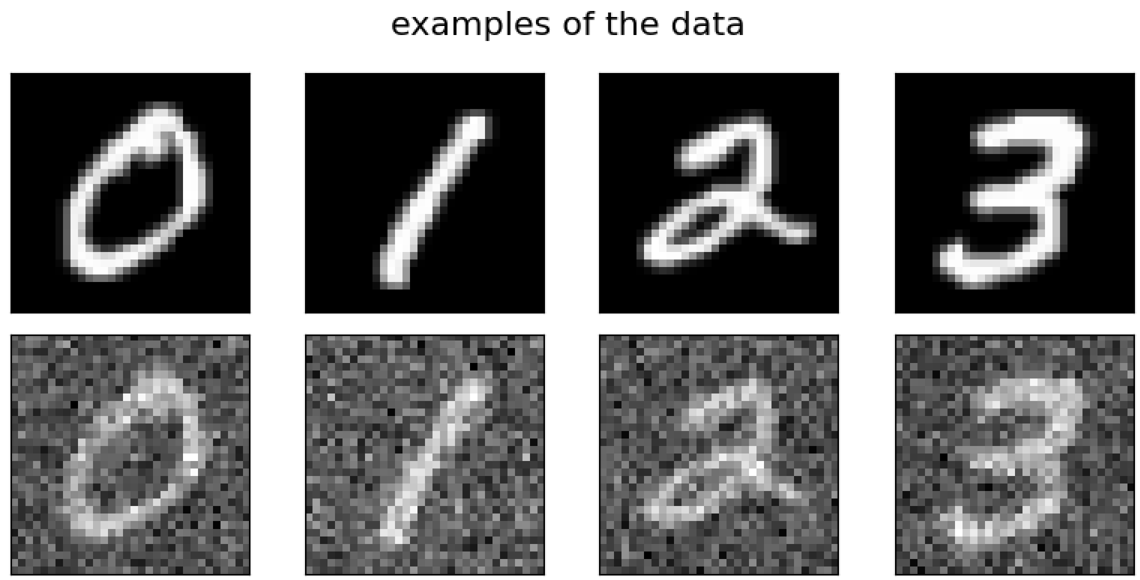
```
print('*************************************************')
print('size of train :', train.shape)
print('size of train_noise :', train_noise.shape)
print('*************************************************')
print('size of test :', test.shape)
print('size of test_noise :', test_noise.shape)
print('*************************************************')
```

```
*************************************************
size of train : (10000, 32, 32)
size of train_noise : (10000, 32, 32)
*************************************************
size of test : (5000, 32, 32)
size of test_noise : (5000, 32, 32)
*************************************************
```

plot examples of the data

In [4]:

```
nRow = 2
nCol = 4
size = 2

title       = 'examples of the data'
fig, axes   = plt.subplots(nRow, nCol, figsize=(size * nCol, size * nRow))
fig.suptitle(title, fontsize=16)

for c in range(nCol):

    axes[0, c].imshow(train[c * 1000], cmap='gray')
    axes[1, c].imshow(train_noise[c * 1000], cmap='gray')

    axes[0, c].xaxis.set_visible(False)
    axes[1, c].xaxis.set_visible(False)

    axes[0, c].yaxis.set_visible(False)
    axes[1, c].yaxis.set_visible(False)

plt.tight_layout()
plt.show()
```



custom data loader for the PyTorch framework

In [5]:

```
class dataset(Dataset):

    def __init__(self, image, image_noise):

        self.image          = image
        self.image_noise    = image_noise

    def __getitem__(self, index):

        image       = self.image[index]
        image_noise = self.image_noise[index]

        image       = torch.FloatTensor(image).unsqueeze(dim=0)
        image_noise = torch.FloatTensor(image_noise).unsqueeze(dim=0)

        return (image, image_noise)

    def __len__(self):

        number_image = self.image.shape[0]

        return number_image
```

setting device

In [6]:

```
device = torch.device('cuda' if torch.cuda.is_available() else 'mps')
```

In [7]:

```
print(device)
```

```
mps
```

In [8]:

```
# random seed for reproducibility
import random
random.seed(20184757)
np.random.seed(20184757)
torch.manual_seed(20184757)
torch.cuda.manual_seed(20184757)
torch.cuda.manual_seed_all(20184757)
torch.backends.cudnn.deterministic = True
torch.backends.cudnn.benchmark = False
```

construct datasets and dataloaders for testing and testing

In [9]:

```
# ==================================================
# determine your own parameter value
#
size_minibatch      = 32
#
# ==================================================

dataset_train       = dataset(train, train_noise)
dataset_test        = dataset(test, test_noise)

dataloader_train    = torch.utils.data.DataLoader(dataset_train, batch_size=size
_minibatch, shuffle=True, drop_last=True)
dataloader_test     = torch.utils.data.DataLoader(dataset_test, batch_size=size_
minibatch, shuffle=True, drop_last=True)
```

shape of the data when using the data loader

In [9]:

```
train_image, train_image_noise = next(iter(dataloader_train))
test_image, test_image_noise = next(iter(dataloader_test))
```

In [10]:

```
print('*************************************************************')
print('size of mini-batch of the training image:', train_image.shape)
print('*************************************************************')
print('size of mini-batch of the training image_noise:', train_image_noise.shape
)
print('*************************************************************')
print('size of mini-batch of the testing image:', test_image.shape)
print('*************************************************************')
print('size of mini-batch of the testing image_noise:', test_image_noise.shape)
print('*************************************************************')
```

```
*************************************************************
size of mini-batch of the training image: torch.Size([32, 1, 32, 3
2])
*************************************************************
size of mini-batch of the training image_noise: torch.Size([32, 1, 3
2, 32])
*************************************************************
size of mini-batch of the testing image: torch.Size([32, 1, 32, 32])
*************************************************************
size of mini-batch of the testing image_noise: torch.Size([32, 1, 3
2, 32])
*************************************************************
```

construct a neural network

In [10]:

```
# ==================================================
# define your own neural network architecture and initialization
#
class Network(nn.Module):
    def __init__(self):
        super(Network,self).__init__()

        # ------------------------------------------------
        # Encoder
        # ------------------------------------------------
        self.encoder_layer1 = nn.Sequential(
            nn.Conv2d(in_channels=1, out_channels=32, kernel_size=3, stride=1, p
adding=1, bias=True),
            nn.MaxPool2d(2,2),
            nn.ReLU(),
            nn.BatchNorm2d(32),
        )

        self.encoder_layer2 = nn.Sequential(
            nn.Conv2d(in_channels=32, out_channels=64, kernel_size=3, stride=1,
padding=1, bias=True),
            nn.MaxPool2d(2,2),
            nn.ReLU(),
            nn.BatchNorm2d(64),
        )

        # ------------------------------------------------
        # Decoder
        # ------------------------------------------------
        self.decoder_layer2 = nn.Sequential(
            nn.Upsample(scale_factor=2, mode='bilinear', align_corners=False),
            nn.Conv2d(in_channels=64, out_channels=32, kernel_size=3, stride=1,
padding=1, bias=True),
            nn.ReLU(),
            nn.BatchNorm2d(32),
        )

        self.decoder_layer1 = nn.Sequential(
            nn.Upsample(scale_factor=2, mode='bilinear', align_corners=False),
            nn.Conv2d(in_channels=32, out_channels=1, kernel_size=3, stride=1, p
adding=1, bias=True),
            nn.Sigmoid(),
        )

        # ------------------------------------------------
        # Network
        # ------------------------------------------------
        self.network = nn.Sequential(
            self.encoder_layer1,
            self.encoder_layer2,
            self.decoder_layer2,
            self.decoder_layer1,
        )

        self.initialize_weight()

    def forward(self,x):
```

```
        out = self.network(x)

        return out

    # ==========================================================================
    # initialize weights
    # ==========================================================================
    def initialize_weight(self):

        for m in self.network.modules():

            if isinstance(m, nn.Conv2d):

                nn.init.xavier_uniform_(m.weight)
                if m.bias is not None:

                    nn.init.constant_(m.bias, 1)
                    pass

            elif isinstance(m, nn.BatchNorm2d):

                nn.init.constant_(m.weight, 1)
                nn.init.constant_(m.bias, 1)

            elif isinstance(m, nn.Linear):

                nn.init.xavier_uniform_(m.weight)

                if m.bias is not None:

                    nn.init.constant_(m.bias, 1)
                    pass
```

build the network

In [11]:

```
# ====================================================
# determine your own parameter value
#
learning_rate   = 0.1
weight_decay    = 0.000001
alpha           = 0.001
number_epoch    = 43
#0.1 0.001 1e-06
# ====================================================

model       = Network().to(device)
optimizer   = torch.optim.Adam(model.parameters(), lr=learning_rate, weight_deca
y=weight_decay)
```

compute the prediction

In [12]:

```
def compute_prediction(model, input):

    prediction = model(input)

    return prediction
```

compute the loss

compute the data fidelity term

- use the mean squared error for the data fidelity term
- use the following loss function `nn.MSELoss()`
- input dimension: mini-batch-size x channel x height x width

In [13]:

```
def compute_loss_data_fidelity(prediction, original):
    # ==================================================
    # fill up the blank
    #
    loss = nn.MSELoss()(prediction, original)
    #
    # ==================================================

    return loss
```

compute the regularization term

- use the total variation for the regularization term
- use the following loss function: $\frac{1}{n} \sum_{x,y} |\frac{\partial}{\partial x} f(x,y)| + \frac{1}{n} \sum_{x,y} |\frac{\partial}{\partial y} f(x,y)|$
- use the neumann boundary condition (gradient of the boundary to the normal direction is zero)

In [14]:

```
def compute_loss_regularization(prediction):
    # ==================================================
    # fill up the blank
    #
    loss = (torch.sum(torch.abs(torch.sub(prediction[:,:,1:,:], prediction[:,:,:
-1,:]))) \
            + torch.sum(torch.abs(torch.sub(prediction[:,:,:,1:], prediction
[:,:,:,:-1])))) \
    / (prediction.size(0) * prediction.size(1) * prediction.size(2) * prediction
.size(3))
    #
    # ==================================================

    return loss
```

compute the total loss

- total loss = data fidelity + α * regularization
- $\alpha \in \mathbb{R}$

In [15]:

```
def compute_loss(prediction, original, alpha):
    # ==================================================
    # fill up the blank
    #
    loss_data_fidelity  = compute_loss_data_fidelity(prediction, original)
    loss_regularization = compute_loss_regularization(prediction)

    loss = loss_data_fidelity + alpha * loss_regularization
    #
    # ==================================================

    return (loss, loss_data_fidelity, loss_regularization)
```

compute the loss value

In [16]:

```
def compute_loss_value(loss):

    loss_value = loss.item()

    return loss_value
```

compute the PSNR metric

- input dimension: mini-batch-size x channel x height x width
- psnr is defined by $10 * \log_{10}(\frac{1}{\text{MSE}})$
- MSE is defined by $\text{MSE}(x, y) = \frac{1}{n} \|x - y\|_2^2$ where n is the length of data x and y

In [17]:

```
def compute_psnr(data1, data2):

    mse         = nn.MSELoss()(data1, data2)
    mse_value   = mse.item()
    psnr        = 10 * np.log10(1 / mse_value)

    return psnr
```

Variable for the learning curves

In [18]:

```
loss_train_mean = np.zeros(number_epoch)
loss_train_std  = np.zeros(number_epoch)
psnr_train_mean = np.zeros(number_epoch)
psnr_train_std  = np.zeros(number_epoch)

loss_test_mean  = np.zeros(number_epoch)
loss_test_std   = np.zeros(number_epoch)
psnr_test_mean  = np.zeros(number_epoch)
psnr_test_std   = np.zeros(number_epoch)

loss_train_data_fidelity_mean   = np.zeros(number_epoch)
loss_train_data_fidelity_std    = np.zeros(number_epoch)
loss_train_regularization_mean  = np.zeros(number_epoch)
loss_train_regularization_std   = np.zeros(number_epoch)

loss_test_data_fidelity_mean    = np.zeros(number_epoch)
loss_test_data_fidelity_std     = np.zeros(number_epoch)
loss_test_regularization_mean   = np.zeros(number_epoch)
loss_test_regularization_std    = np.zeros(number_epoch)
```

train

In [19]:

```
def train(model, optimizer, dataloader):

    loss_epoch                  = []
    loss_data_fidelity_epoch    = []
    loss_regularization_epoch   = []
    psnr_epoch                  = []

    model.train()

    for index_batch, (image, image_noise) in enumerate(dataloader):

        image       = image.to(device)
        image_noise = image_noise.to(device)

        # ==================================================
        # fill up the blank
        #
        prediction                  = compute_prediction(model, image_noise)
        loss_all                    = compute_loss(prediction, image_noise, alph
a)
        loss_value                  = compute_loss_value(loss_all[0])
        loss_data_fidelity_value    = compute_loss_value(loss_all[1])
        loss_regularization_value   = compute_loss_value(loss_all[2])
        psnr                        = compute_psnr(prediction, image)
        #
        # ==================================================

        loss_epoch.append(loss_value)
        loss_data_fidelity_epoch.append(loss_data_fidelity_value)
        loss_regularization_epoch.append(loss_regularization_value)
        psnr_epoch.append(psnr)

        # ==================================================
        # fill up the blank (update moodel parameters)
        #
        optimizer.zero_grad()
        loss_all[0].backward()
        optimizer.step()
        #
        # ==================================================

    loss_mean   = np.mean(loss_epoch)
    loss_std    = np.std(loss_epoch)

    loss_data_fidelity_mean = np.mean(loss_data_fidelity_epoch)
    loss_data_fidelity_std  = np.std(loss_data_fidelity_epoch)

    loss_regularization_mean    = np.mean(loss_regularization_epoch)
    loss_regularization_std     = np.std(loss_regularization_epoch)

    psnr_mean   = np.mean(psnr_epoch)
    psnr_std    = np.std(psnr_epoch)

    loss                = {'mean' : loss_mean, 'std' : loss_std}
    loss_data_fidelity  = {'mean' : loss_data_fidelity_mean, 'std' : loss_data_f
idelity_std}
    loss_regularization = {'mean' : loss_regularization_mean, 'std' : loss_regul
```

```
arization_std}
    psnr                = {'mean' : psnr_mean, 'std' : psnr_std}

    return (loss, loss_data_fidelity, loss_regularization, psnr)
```

test

In [20]:

```
def test(model, dataloader):

    loss_epoch                      = []
    loss_data_fidelity_epoch        = []
    loss_regularization_epoch       = []
    psnr_epoch                      = []

    model.eval()

    for index_batch, (image, image_noise) in enumerate(dataloader):

        image       = image.to(device)
        image_noise = image_noise.to(device)

        # ==================================================
        # fill up the blank
        #
        prediction                      = compute_prediction(model, image_noise)
        loss_all                        = compute_loss(prediction, image_noise, alph
a)
        loss_value                      = compute_loss_value(loss_all[0])
        loss_data_fidelity_value        = compute_loss_value(loss_all[1])
        loss_regularization_value       = compute_loss_value(loss_all[2])
        psnr                            = compute_psnr(prediction, image)
        #
        # ==================================================

        loss_epoch.append(loss_value)
        loss_data_fidelity_epoch.append(loss_data_fidelity_value)
        loss_regularization_epoch.append(loss_regularization_value)
        psnr_epoch.append(psnr)

    loss_mean   = np.mean(loss_epoch)
    loss_std    = np.std(loss_epoch)

    loss_data_fidelity_mean = np.mean(loss_data_fidelity_epoch)
    loss_data_fidelity_std  = np.std(loss_data_fidelity_epoch)

    loss_regularization_mean    = np.mean(loss_regularization_epoch)
    loss_regularization_std     = np.std(loss_regularization_epoch)

    psnr_mean   = np.mean(psnr_epoch)
    psnr_std    = np.std(psnr_epoch)

    loss                = {'mean' : loss_mean, 'std' : loss_std}
    loss_data_fidelity  = {'mean' : loss_data_fidelity_mean, 'std' : loss_data_f
idelity_std}
    loss_regularization = {'mean' : loss_regularization_mean, 'std' : loss_regul
arization_std}
    psnr                = {'mean' : psnr_mean, 'std' : psnr_std}

    return (loss, loss_data_fidelity, loss_regularization, psnr)
```

train and test

In [21]:

```
# ============================================================================
==
#
# iterations for epochs
#
# ============================================================================
==
for i in tqdm(range(number_epoch)):

    # ========================================================================
======
    #
    # training
    #
    # ========================================================================
======
    (loss_train, loss_data_fidelity_train, loss_regularization_train, psnr_train
) = train(model, optimizer, dataloader_train)

    loss_train_mean[i]  = loss_train['mean']
    loss_train_std[i]   = loss_train['std']

    loss_train_data_fidelity_mean[i]    = loss_data_fidelity_train['mean']
    loss_train_data_fidelity_std[i]     = loss_data_fidelity_train['std']

    loss_train_regularization_mean[i]   = loss_regularization_train['mean']
    loss_train_regularization_std[i]    = loss_regularization_train['std']

    psnr_train_mean[i]  = psnr_train['mean']
    psnr_train_std[i]   = psnr_train['std']

    # ========================================================================
======
    #
    # testing
    #
    # ========================================================================
======
    (loss_test, loss_data_fidelity_test, loss_regularization_test, psnr_test) =
test(model, dataloader_test)

    loss_test_mean[i]  = loss_test['mean']
    loss_test_std[i]   = loss_test['std']

    loss_test_data_fidelity_mean[i]    = loss_data_fidelity_test['mean']
    loss_test_data_fidelity_std[i]     = loss_data_fidelity_test['std']

    loss_test_regularization_mean[i]   = loss_regularization_test['mean']
    loss_test_regularization_std[i]    = loss_regularization_test['std']

    psnr_test_mean[i]  = psnr_test['mean']
    psnr_test_std[i]   = psnr_test['std']
```

```
  0%|                                                    | 0/43 [00:
00<?, ?it/s]/opt/homebrew/lib/python3.10/site-packages/torch/autogra
d/__init__.py:173: UserWarning: The operator 'aten::sgn.out' is not
currently supported on the MPS backend and will fall back to run on
the CPU. This may have performance implications. (Triggered internal
ly at  /Users/runner/work/pytorch/pytorch/pytorch/aten/src/ATen/mps/
MPSFallback.mm:11.)
  Variable._execution_engine.run_backward(  # Calls into the C++ eng
ine to run the backward pass
100%|██████████████████████████████████████████| 43/43 [05:51<00:0
0,  8.18s/it]
```

functions for presenting the results

In [22]:

```python
def function_result_01():

    title           = 'loss (training)'
    label_axis_x    = 'epoch'
    label_axis_y    = 'loss'
    color_mean      = 'red'
    color_std       = 'blue'
    alpha           = 0.3

    plt.figure(figsize=(8, 6))
    plt.title(title)

    plt.plot(range(len(loss_train_mean)), loss_train_mean, '-', color = color_me
an)
    plt.fill_between(range(len(loss_train_mean)), loss_train_mean - loss_train_s
td, loss_train_mean + loss_train_std, facecolor = color_std, alpha = alpha)

    plt.xlabel(label_axis_x)
    plt.ylabel(label_axis_y)

    plt.tight_layout()
    plt.show()
```

In [23]:

```
def function_result_02():

    title           = 'loss - data fidelity (training)'
    label_axis_x    = 'epoch'
    label_axis_y    = 'loss'
    color_mean      = 'red'
    color_std       = 'blue'
    alpha           = 0.3

    plt.figure(figsize=(8, 6))
    plt.title(title)

    plt.plot(range(len(loss_train_data_fidelity_mean)), loss_train_data_fidelity
_mean, '-', color = color_mean)
    plt.fill_between(range(len(loss_train_data_fidelity_mean)), loss_train_data_
fidelity_mean - loss_train_data_fidelity_std, loss_train_data_fidelity_mean + lo
ss_train_data_fidelity_std, facecolor = color_std, alpha = alpha)

    plt.xlabel(label_axis_x)
    plt.ylabel(label_axis_y)

    plt.tight_layout()
    plt.show()
```

In [24]:

```
def function_result_03():

    title           = 'loss - regularization (training)'
    label_axis_x    = 'epoch'
    label_axis_y    = 'loss'
    color_mean      = 'red'
    color_std       = 'blue'
    alpha           = 0.3

    plt.figure(figsize=(8, 6))
    plt.title(title)

    plt.plot(range(len(loss_train_regularization_mean)), loss_train_regularizati
on_mean, '-', color = color_mean)
    plt.fill_between(range(len(loss_train_regularization_mean)), loss_train_regu
larization_mean - loss_train_regularization_std, loss_train_regularization_mean
+ loss_train_regularization_std, facecolor = color_std, alpha = alpha)

    plt.xlabel(label_axis_x)
    plt.ylabel(label_axis_y)

    plt.tight_layout()
    plt.show()
```

In [25]:

```
def function_result_04():

    title           = 'loss (testing)'
    label_axis_x    = 'epoch'
    label_axis_y    = 'loss'
    color_mean      = 'red'
    color_std       = 'blue'
    alpha           = 0.3

    plt.figure(figsize=(8, 6))
    plt.title(title)

    plt.plot(range(len(loss_test_mean)), loss_test_mean, '-', color = color_mean
)
    plt.fill_between(range(len(loss_test_mean)), loss_test_mean - loss_test_std,
loss_test_mean + loss_test_std, facecolor = color_std, alpha = alpha)

    plt.xlabel(label_axis_x)
    plt.ylabel(label_axis_y)

    plt.tight_layout()
    plt.show()
```

In [26]:

```
def function_result_05():

    title           = 'loss - data fidelity (testing)'
    label_axis_x    = 'epoch'
    label_axis_y    = 'loss'
    color_mean      = 'red'
    color_std       = 'blue'
    alpha           = 0.3

    plt.figure(figsize=(8, 6))
    plt.title(title)

    plt.plot(range(len(loss_test_data_fidelity_mean)), loss_test_data_fidelity_m
ean, '-', color = color_mean)
    plt.fill_between(range(len(loss_test_data_fidelity_mean)), loss_test_data_fi
delity_mean - loss_test_data_fidelity_std, loss_test_data_fidelity_mean + loss_t
est_data_fidelity_std, facecolor = color_std, alpha = alpha)

    plt.xlabel(label_axis_x)
    plt.ylabel(label_axis_y)

    plt.tight_layout()
    plt.show()
```

In [27]:

```
def function_result_06():

    title           = 'loss - regularization (testing)'
    label_axis_x    = 'epoch'
    label_axis_y    = 'loss'
    color_mean      = 'red'
    color_std       = 'blue'
    alpha           = 0.3

    plt.figure(figsize=(8, 6))
    plt.title(title)

    plt.plot(range(len(loss_test_regularization_mean)), loss_test_regularization
_mean, '-', color = color_mean)
    plt.fill_between(range(len(loss_test_regularization_mean)), loss_test_regula
rization_mean - loss_test_regularization_std, loss_test_regularization_mean + lo
ss_test_regularization_std, facecolor = color_std, alpha = alpha)

    plt.xlabel(label_axis_x)
    plt.ylabel(label_axis_y)

    plt.tight_layout()
    plt.show()
```

In [28]:

```
def function_result_07():

    title           = 'psnr (training)'
    label_axis_x    = 'epoch'
    label_axis_y    = 'psnr'
    color_mean      = 'red'
    color_std       = 'blue'
    alpha           = 0.3

    plt.figure(figsize=(8, 6))
    plt.title(title)

    plt.plot(range(len(psnr_train_mean)), psnr_train_mean, '-', color = color_me
an)
    plt.fill_between(range(len(psnr_train_mean)), psnr_train_mean - psnr_train_s
td, psnr_train_mean + psnr_train_std, facecolor = color_std, alpha = alpha)

    plt.xlabel(label_axis_x)
    plt.ylabel(label_axis_y)

    plt.tight_layout()
    plt.show()
```

In [29]:

```
def function_result_08():

    title           = 'psnr (testing)'
    label_axis_x    = 'epoch'
    label_axis_y    = 'psnr'
    color_mean      = 'red'
    color_std       = 'blue'
    alpha           = 0.3

    plt.figure(figsize=(8, 6))
    plt.title(title)

    plt.plot(range(len(psnr_test_mean)), psnr_test_mean, '-', color = color_mean
)
    plt.fill_between(range(len(psnr_test_mean)), psnr_test_mean - psnr_test_std,
psnr_test_mean + psnr_test_std, facecolor = color_std, alpha = alpha)

    plt.xlabel(label_axis_x)
    plt.ylabel(label_axis_y)

    plt.tight_layout()
    plt.show()
```

In [30]:

```
def function_result_09():

    nRow = 9
    nCol = 3
    size = 3

    title = 'training results'
    fig, axes = plt.subplots(nRow, nCol, figsize=(size * nCol, size * nRow))
    fig.suptitle(title, fontsize=16)

    index_image = np.array([0, 1000, 2000, 3000, 4000, 5000, 6000, 7000, 8000])

    image            = torch.FloatTensor(dataset_train.image[index_image]).unsque
eze(dim=1).to(device)
    image_noise      = torch.FloatTensor(dataset_train.image_noise[index_image]).
unsqueeze(dim=1).to(device)
    image_denoise    = compute_prediction(model, image_noise)

    image            = image.detach().cpu().squeeze(axis=1)
    image_noise      = image_noise.detach().cpu().squeeze(axis=1)
    image_denoise    = image_denoise.detach().cpu().squeeze(axis=1)

    nStep = 3

    for r in range(3):
        for c in range(nCol):

            axes[0 + r * nStep, c].imshow(image_noise[c + r * nStep], cmap='gra
y')
            axes[1 + r * nStep, c].imshow(image[c + r * nStep], cmap='gray', vmi
n=0, vmax=1)
            axes[2 + r * nStep, c].imshow(image_denoise[c + r * nStep], cmap='gr
ay', vmin=0, vmax=1)

            axes[0 + r * nStep, c].xaxis.set_visible(False)
            axes[1 + r * nStep, c].xaxis.set_visible(False)
            axes[2 + r * nStep, c].xaxis.set_visible(False)

            axes[0 + r * nStep, c].yaxis.set_visible(False)
            axes[1 + r * nStep, c].yaxis.set_visible(False)
            axes[2 + r * nStep, c].yaxis.set_visible(False)

    plt.tight_layout()
    plt.show()
```

In [31]:

```
def function_result_10():

    nRow = 9
    nCol = 3
    size = 3

    title = 'testing results'
    fig, axes = plt.subplots(nRow, nCol, figsize=(size * nCol, size * nRow))
    fig.suptitle(title, fontsize=16)

    index_image     = np.array([0, 500, 1000, 1500, 2000, 2500, 3000, 3500, 4000
])

    image           = torch.FloatTensor(dataset_test.image[index_image]).unsquee
ze(dim=1).to(device)
    image_noise     = torch.FloatTensor(dataset_test.image_noise[index_image]).u
nsqueeze(dim=1).to(device)
    image_denoise   = compute_prediction(model, image_noise)

    image           = image.detach().cpu().squeeze(axis=1)
    image_noise     = image_noise.detach().cpu().squeeze(axis=1)
    image_denoise   = image_denoise.detach().cpu().squeeze(axis=1)

    nStep = 3

    for r in range(3):
        for c in range(nCol):

            axes[0 + r * nStep, c].imshow(image_noise[c + r * nStep], cmap='gra
y')
            axes[1 + r * nStep, c].imshow(image[c + r * nStep], cmap='gray', vmi
n=0, vmax=1)
            axes[2 + r * nStep, c].imshow(image_denoise[c + r * nStep], cmap='gr
ay', vmin=0, vmax=1)

            axes[0 + r * nStep, c].xaxis.set_visible(False)
            axes[1 + r * nStep, c].xaxis.set_visible(False)
            axes[2 + r * nStep, c].xaxis.set_visible(False)

            axes[0 + r * nStep, c].yaxis.set_visible(False)
            axes[1 + r * nStep, c].yaxis.set_visible(False)
            axes[2 + r * nStep, c].yaxis.set_visible(False)

    plt.tight_layout()
    plt.show()
```

In [32]:

```
def function_result_11():

    print('final training psnr = %9.8f' % (psnr_train_mean[-1]))
```

In [33]:

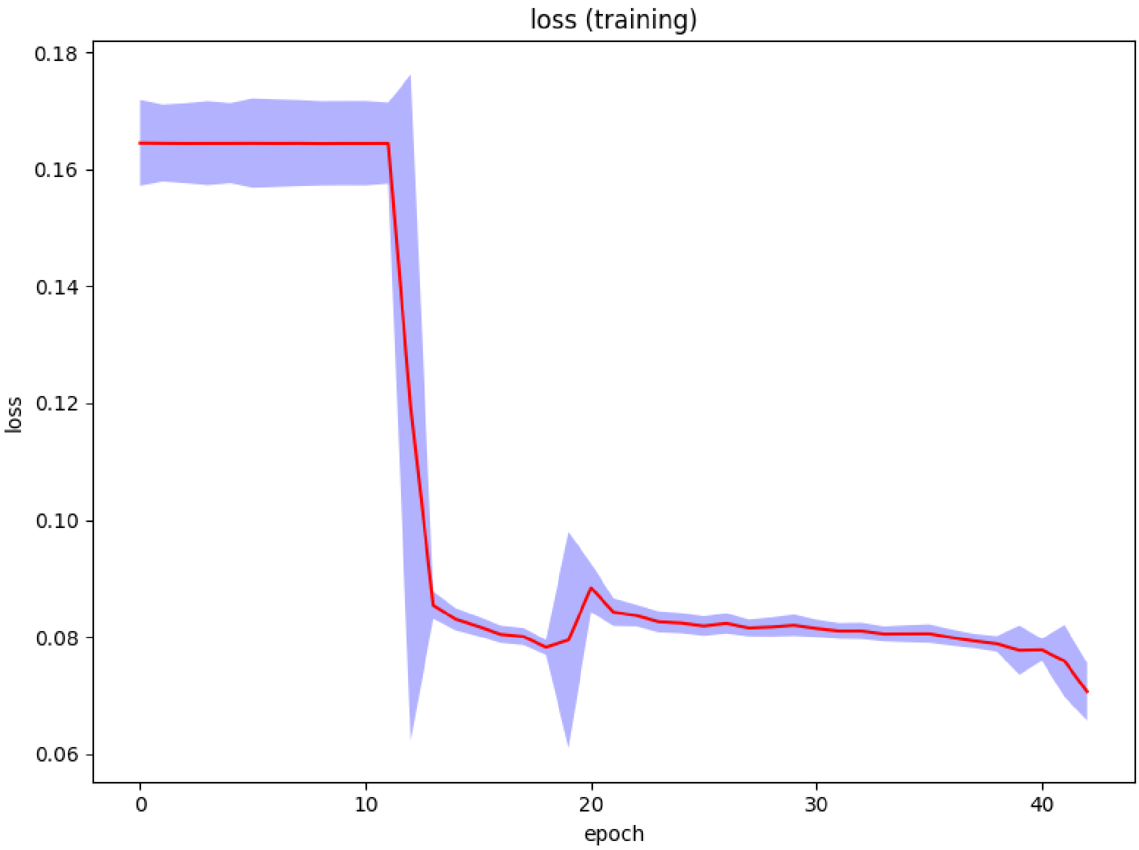
```
def function_result_12():

    print('final testing psnr = %9.8f' % (psnr_test_mean[-1]))
```

results

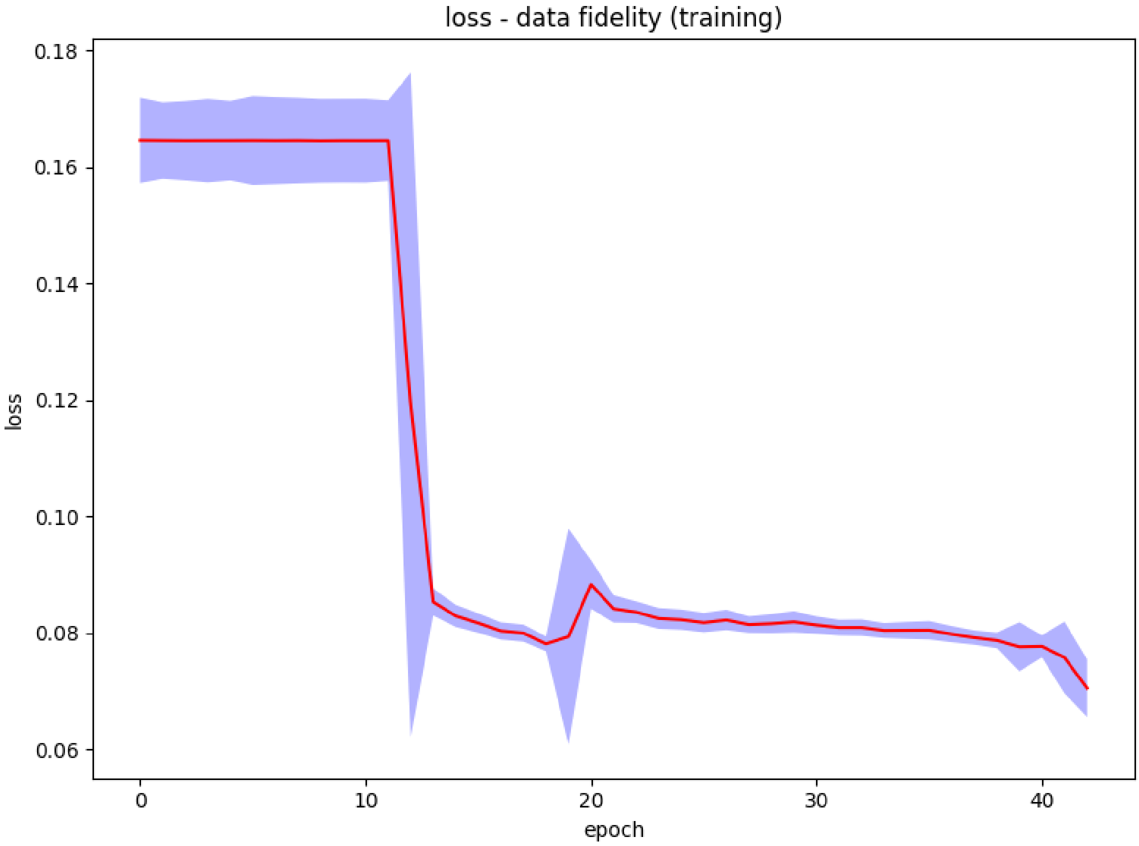
In [34]:

```
number_result = 12

for i in range(number_result):

    title           = '# RESULT # {:02d}'.format(i+1)
    name_function   = 'function_result_{:02d}()'.format(i+1)

    print('')
    print('#####################################################################
###########')
    print('#')
    print(title)
    print('#')
    print('#####################################################################
###########')
    print('')

    eval(name_function)
```

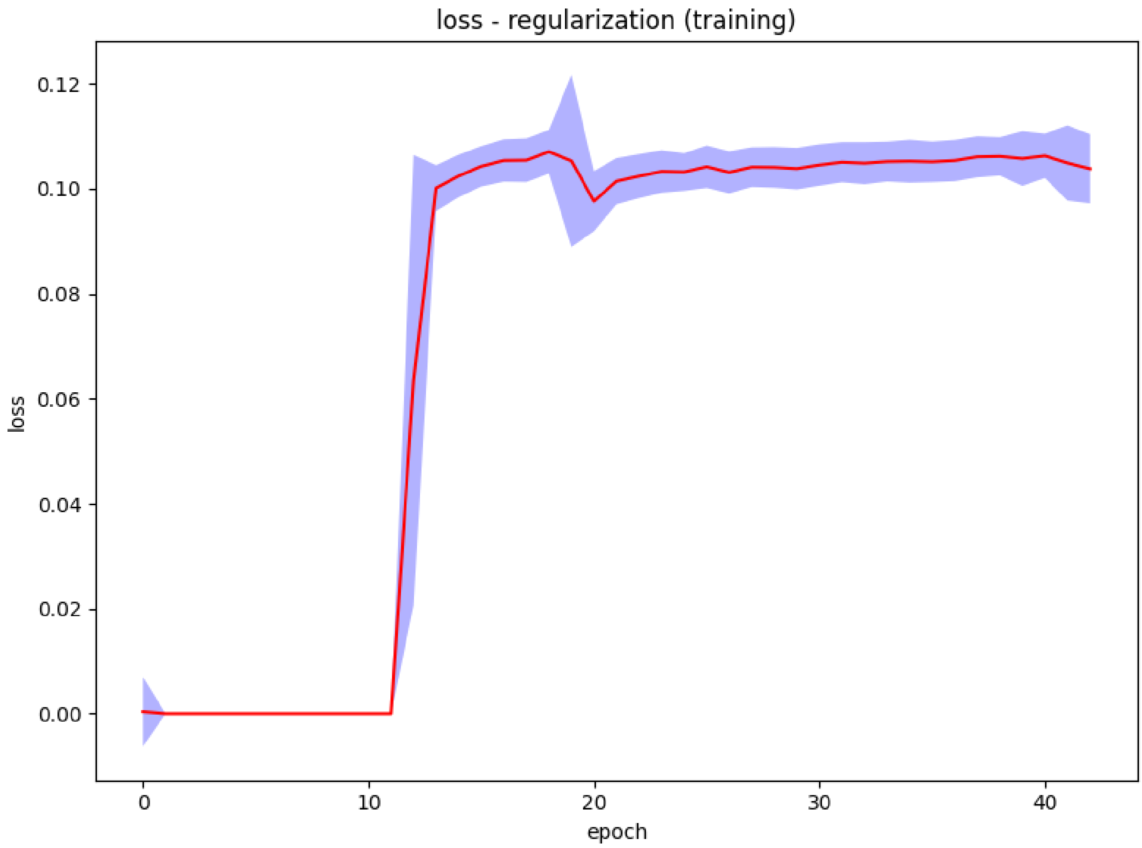
```
########################################################################
#
# RESULT # 01
#
########################################################################
```



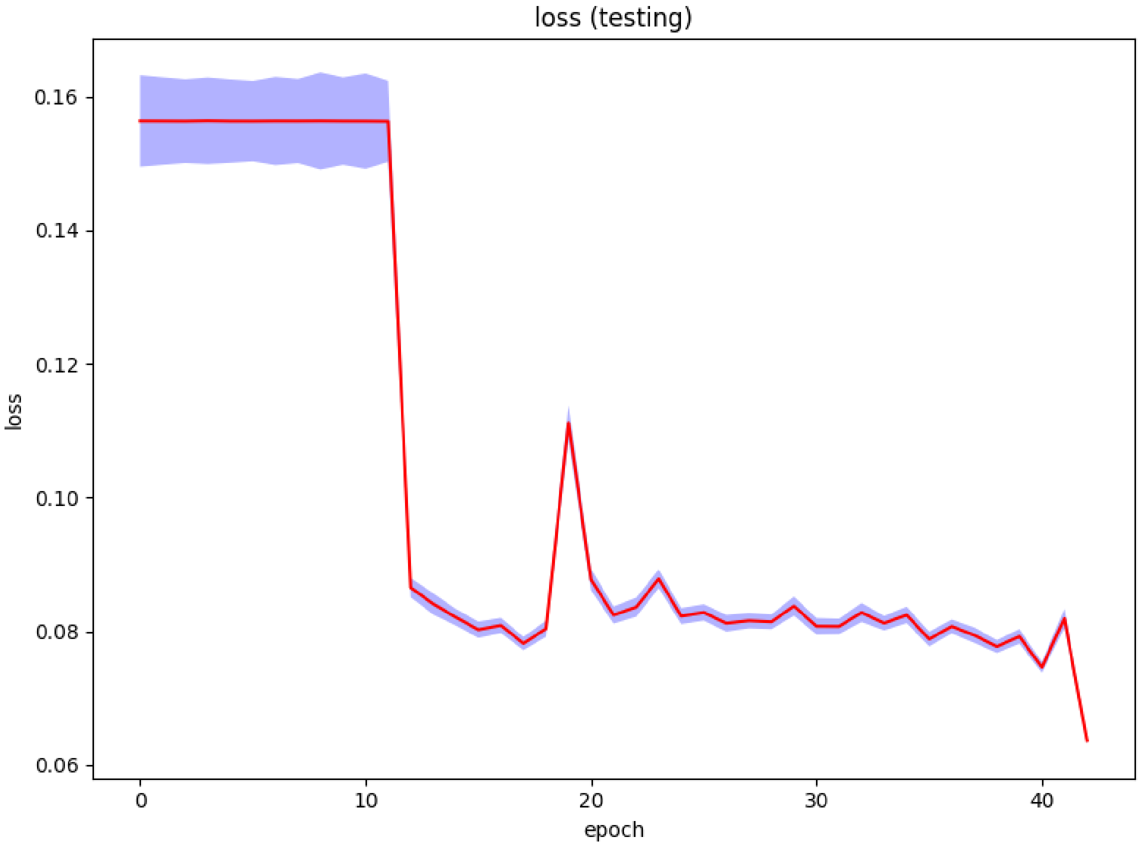

```
########################################################################
#
# RESULT # 02
#
########################################################################
```


loss - data fidelity (training)
0.18
0.16
0.14
0.12
0.10
0.08
0.06
loss
0
10
20
30
40
epoch

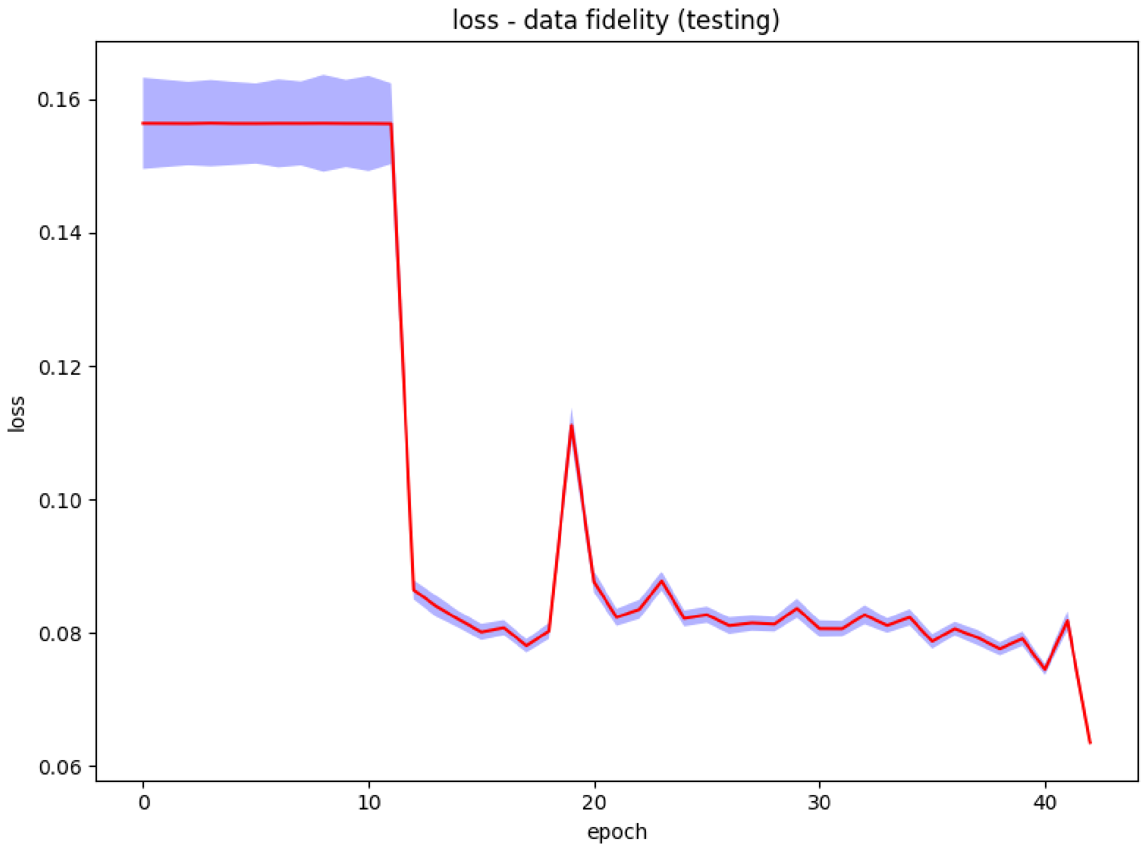
```
########################################################################
############
#
# RESULT # 03
#
########################################################################
############
```


loss - regularization (training)
0.12
0.10
0.08
0.06
0.04
0.02
0.00
loss
0
10
20
30
40
epoch

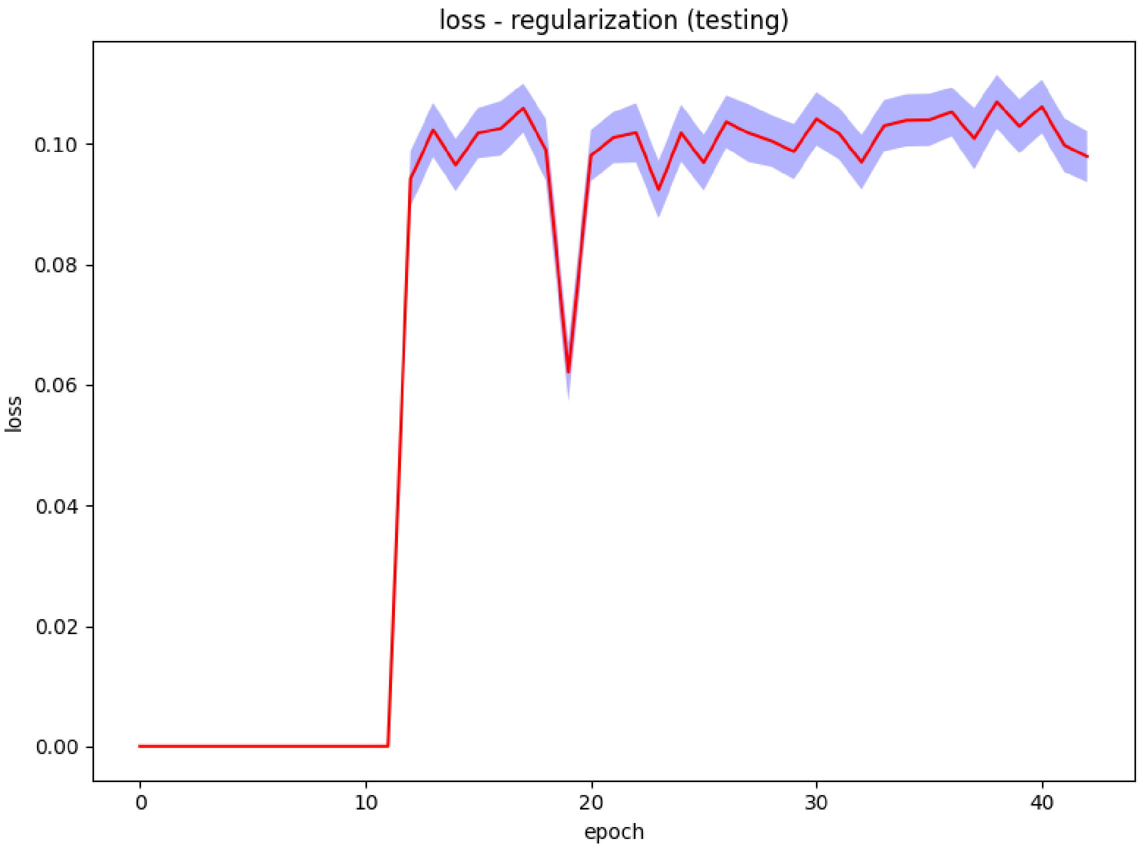
```
#######################################################################
############
#
# RESULT # 04
#
#######################################################################
############
```



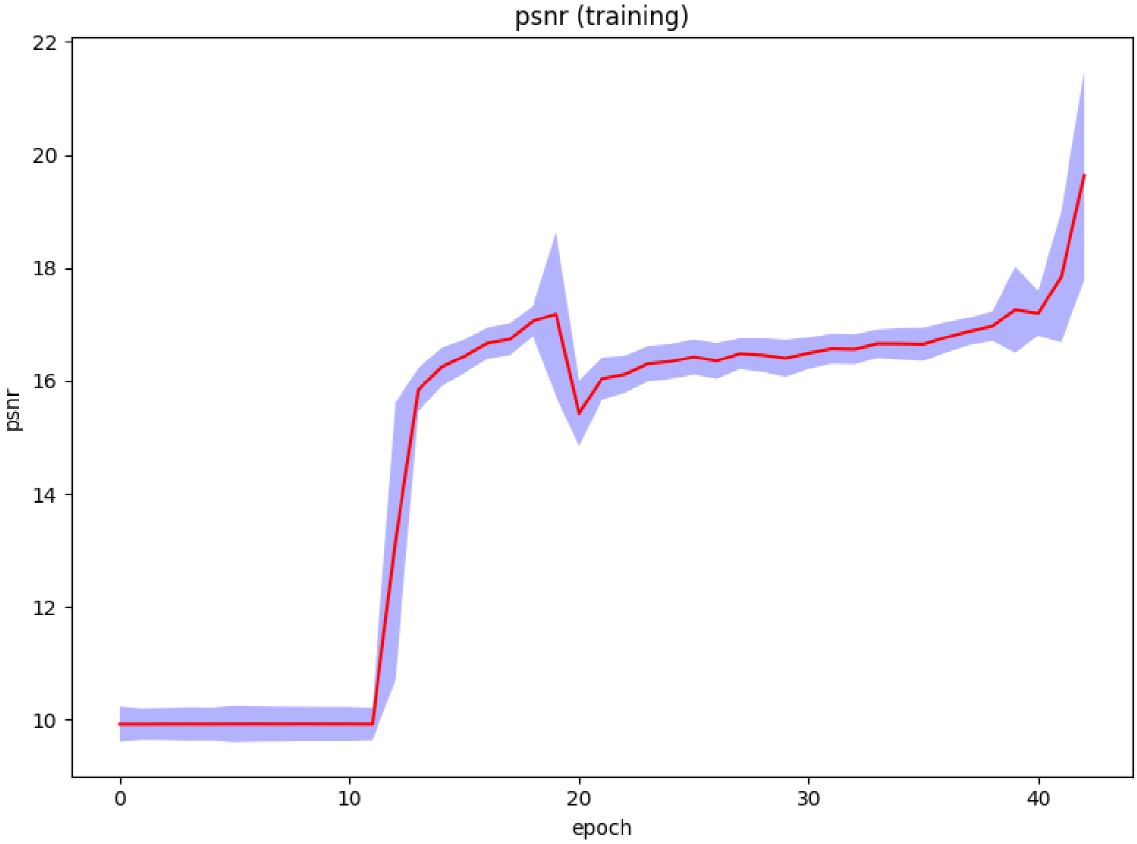

```
##################################################################
###########
#
# RESULT # 05
#
##################################################################
###########
```


loss - data fidelity (testing)
0.16
0.14
0.12
0.10
0.08
0.06
loss
0
10
20
30
40
epoch

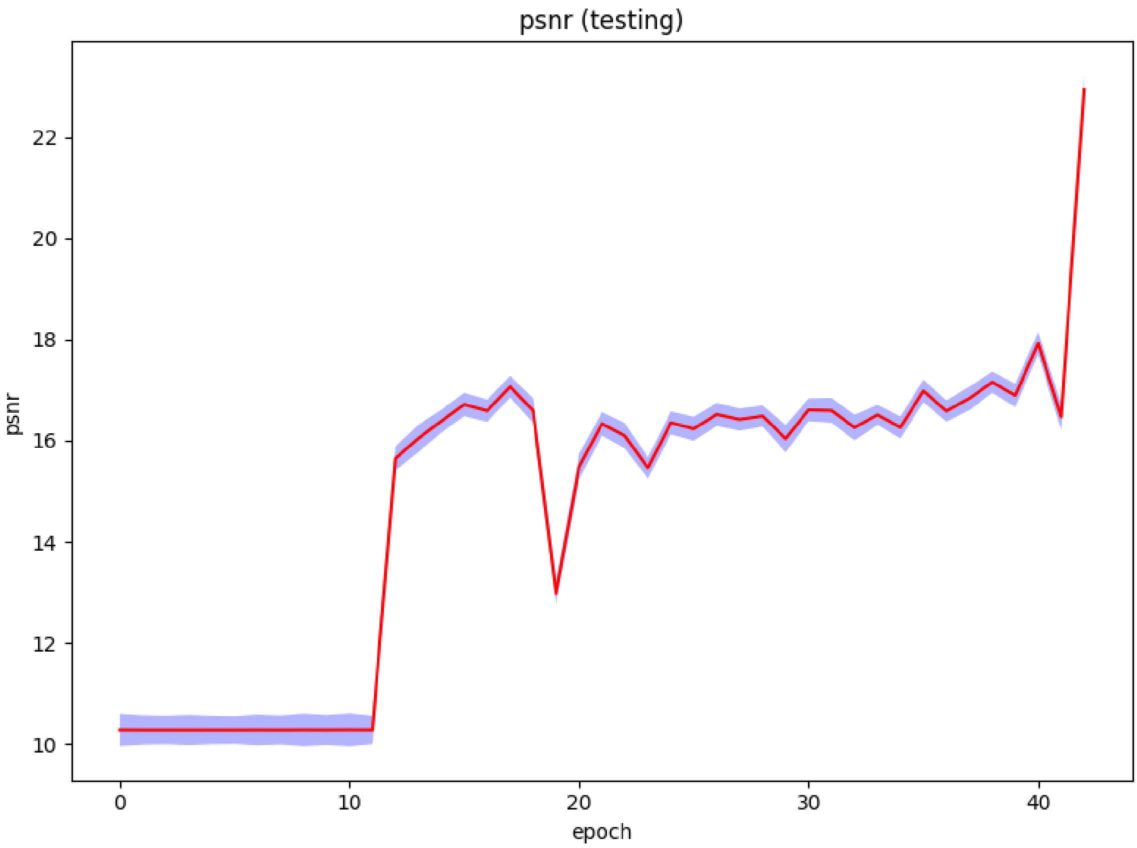
```
########################################################################
############
#
# RESULT # 06
#
########################################################################
############
```


loss - regularization (testing)
0.10
0.08
0.06
0.04
0.02
0.00
loss
0
10
20
30
40
epoch

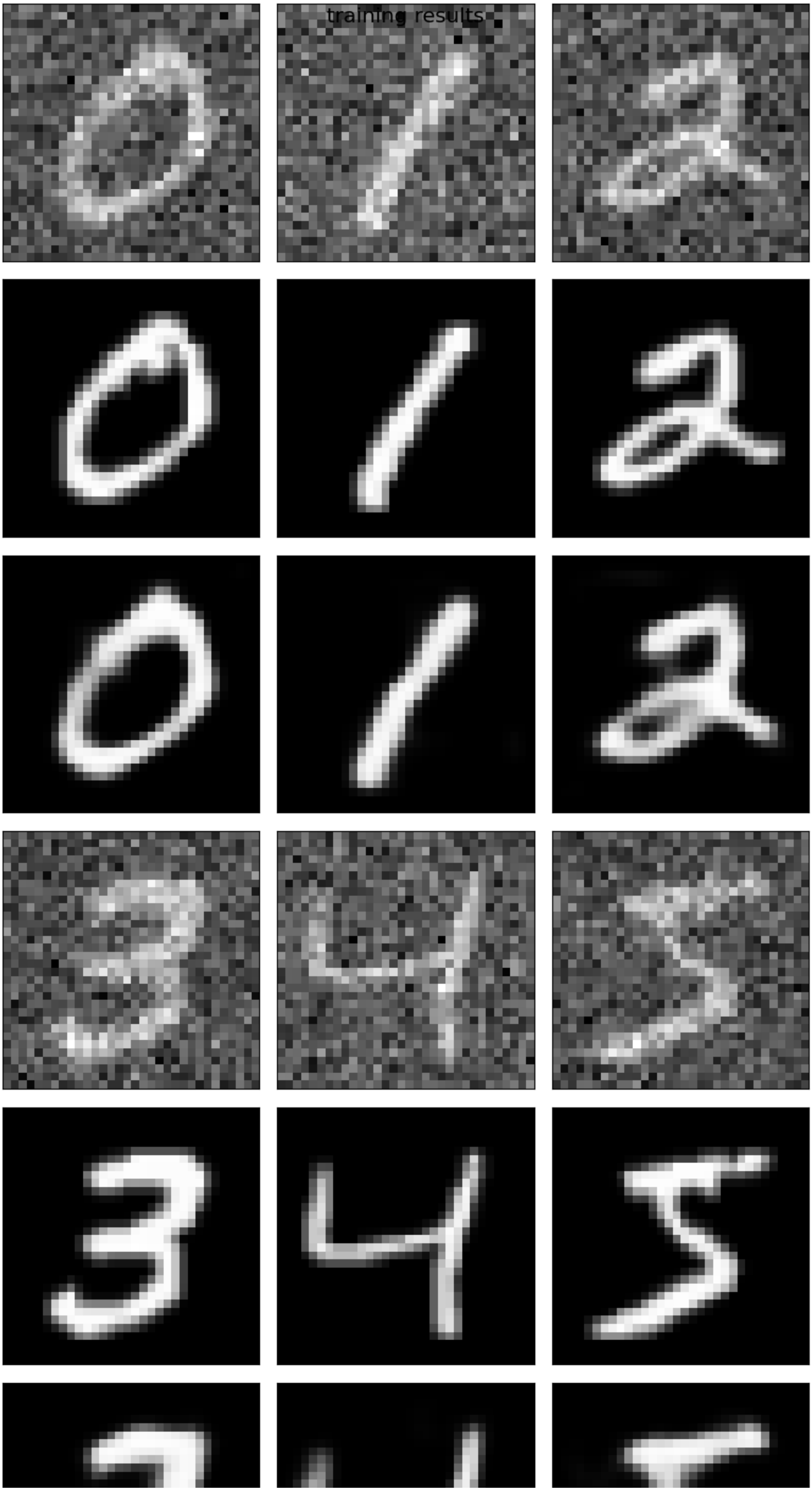
```
########################################################################
#
# RESULT # 07
#
########################################################################
```

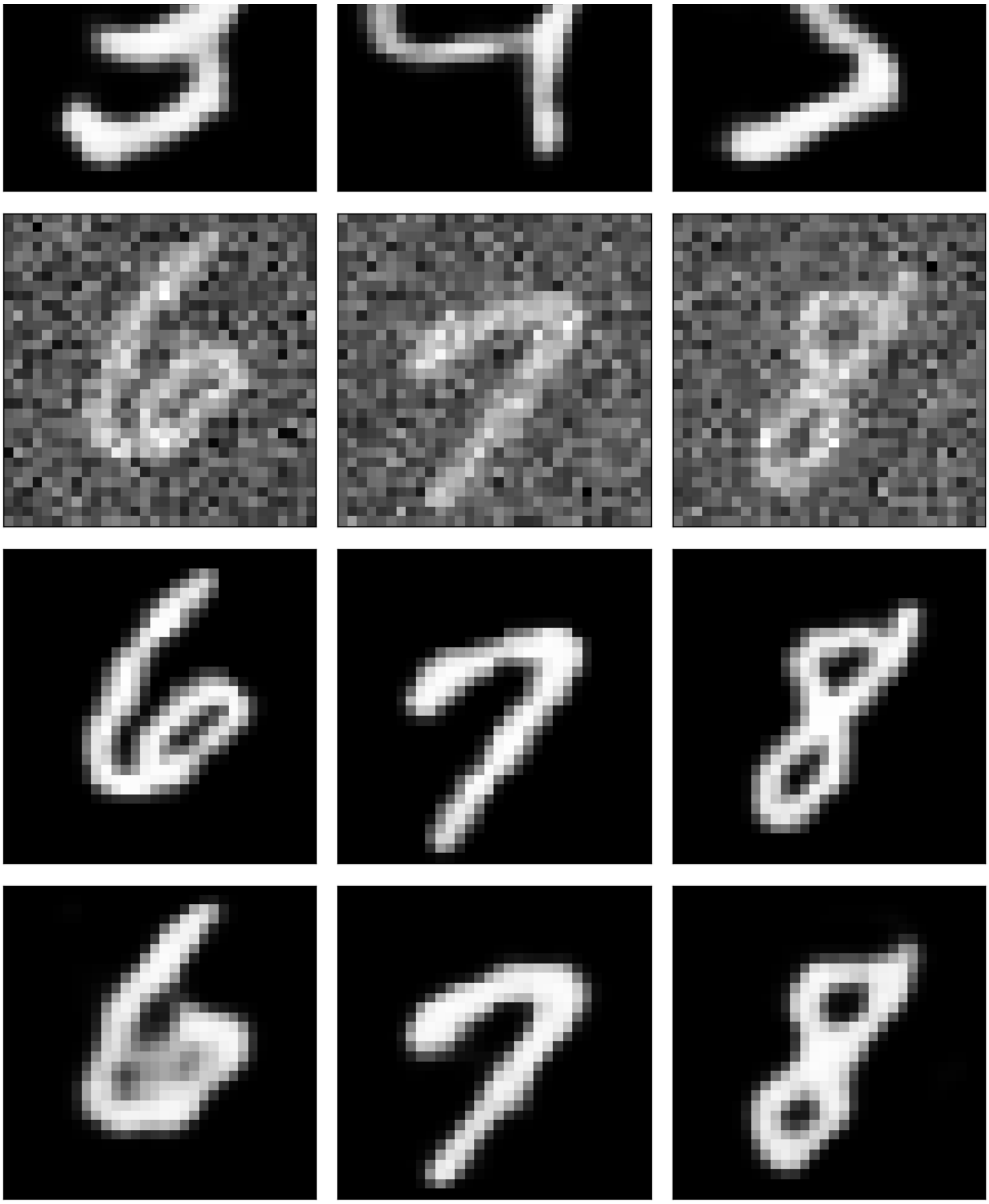



```
########################################################################
############
#
# RESULT # 08
#
########################################################################
############
```

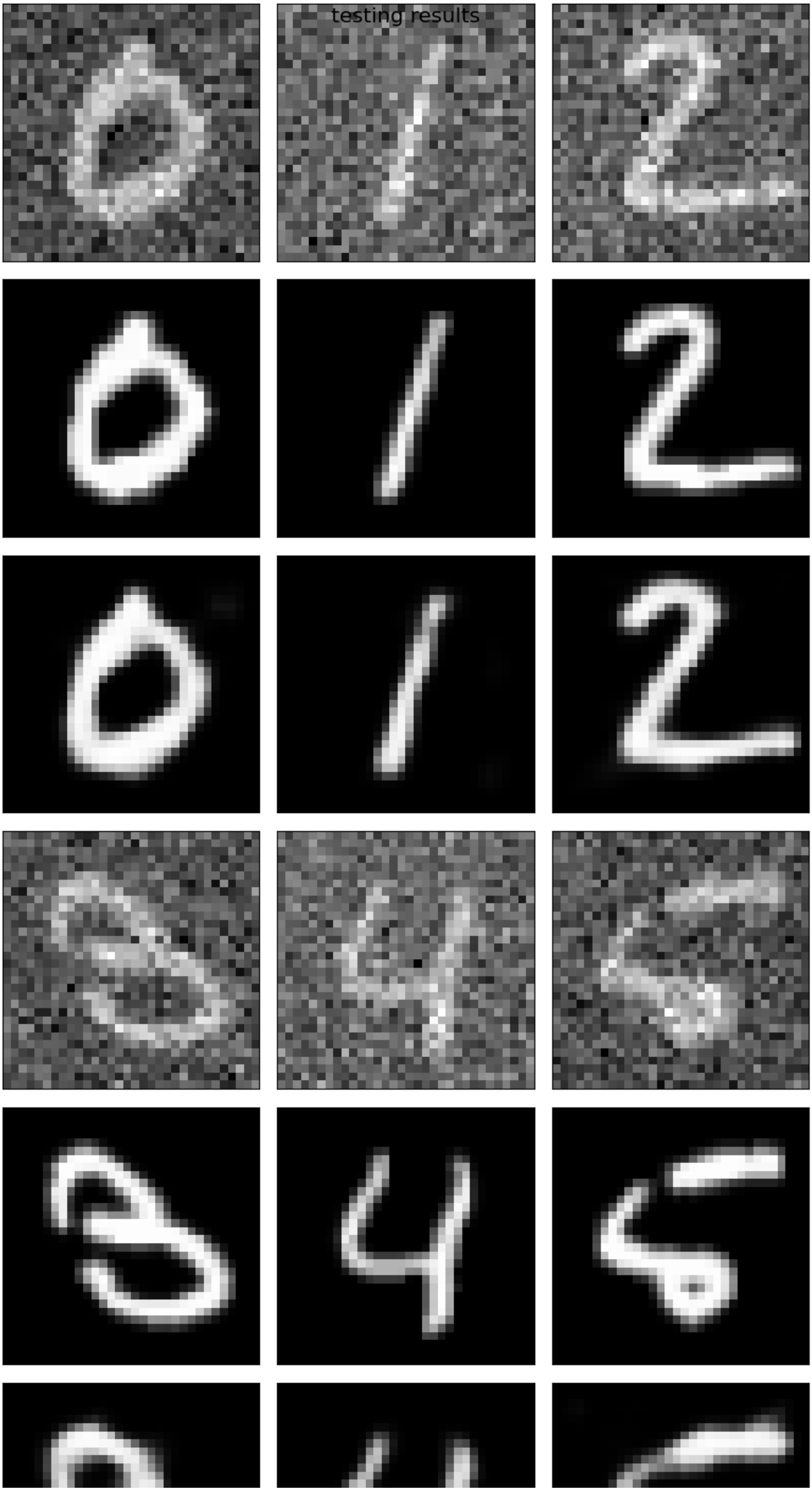


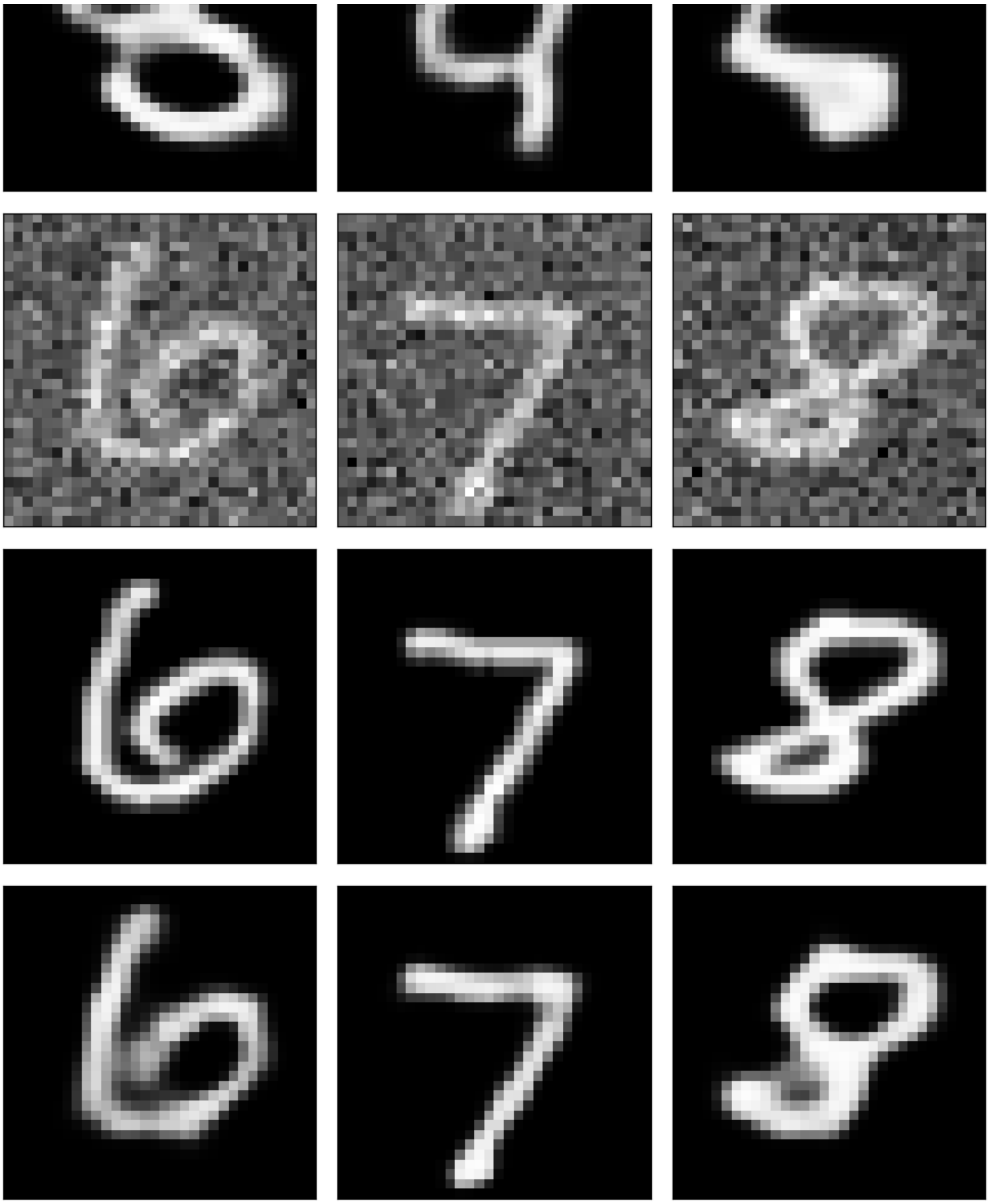

```
####################################################################
############
#
# RESULT # 09
#
####################################################################
############
```


training results



```
####################################################################
############
#
# RESULT # 10
#
####################################################################
############
```


testing results



```
########################################################################
############
#
# RESULT # 11
#
########################################################################
############

final training psnr = 19.63160151

########################################################################
############
#
# RESULT # 12
#
########################################################################
############

final testing psnr = 22.94414897
```