Image Generation via Generative Adversarial Networks

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 import datasets, transforms
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_12_data.npz'
data            = np.load(os.path.join(directory_data, filename_data))
real            = data['real_images']
```

In [3]:

```
print('size of real data:', real.shape)
```

```
size of real data: (4324, 32, 32)
```

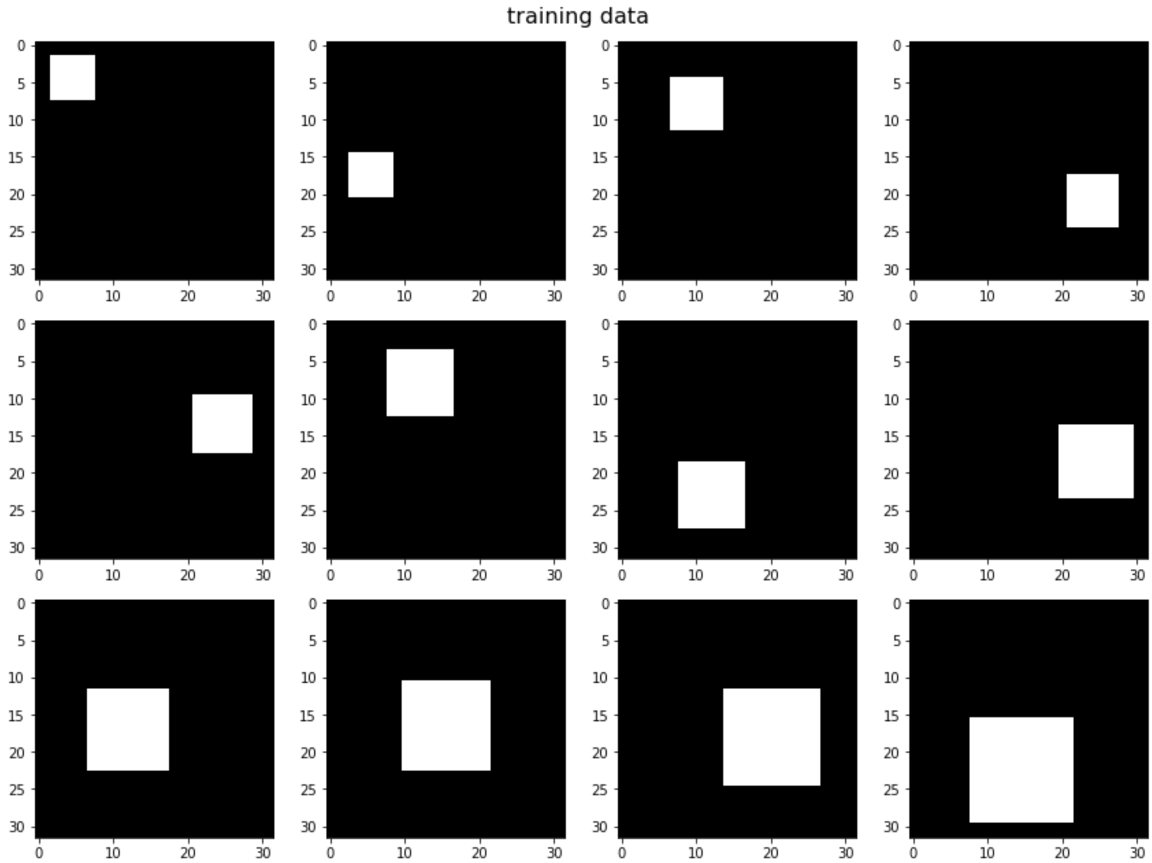
plot data

In [4]:

```
def plot_image(title, image):

    nRow = 3
    nCol = 4
    size = 3

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

    for r in range(nRow):
        for c in range(nCol):
            k = c * 300 + r * nCol * 300
            axes[r, c].imshow(image[k], cmap='gray')

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

In [5]:

```
plot_image('training data', real)
```



custom data loader for the PyTorch framework

In [6]:

```
class dataset(Dataset):

    def __init__(self, image):

        self.image = image

    def __getitem__(self, index):

        sample  = self.image[index]
        sample  = torch.FloatTensor(sample).unsqueeze(dim=0)

        return (sample)

    def __len__(self):

        number_image = len(self.image)

        return (number_image)
```

setting device

In [7]:

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

In [8]:

```
print(device)
```

cuda

In [9]:

```
# random seed
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

In [10]:

```
size_minibatch  = 32
dim_latent      = 64 # input latent vector fixed dimension

dataset_real    = dataset(real)
dataloader_real = torch.utils.data.DataLoader(dataset_real, batch_size=size_mini
batch, shuffle=True, drop_last=True)
```

neural networks

In [11]:

```
class Discriminator(nn.Module):

    def __init__(self):

        super(Discriminator, self).__init__()

        self.conv = nn.Sequential(
            nn.Conv2d(in_channels=1, out_channels=16, kernel_size=3, stride=2, p
adding=1, bias=True),
            nn.LeakyReLU(0.2),

            nn.Conv2d(in_channels=16, out_channels=32, kernel_size=3, stride=2,
padding=1, bias=True),
            nn.LeakyReLU(0.2),

            nn.Conv2d(in_channels=32, out_channels=64, kernel_size=3, stride=2,
padding=1, bias=True),
            nn.LeakyReLU(0.2),

            nn.Conv2d(in_channels=64, out_channels=128, kernel_size=3, stride=2,
padding=1, bias=True),
            nn.LeakyReLU(0.2),

            nn.Conv2d(in_channels=128, out_channels=256, kernel_size=3, stride=
2, padding=1, bias=True),
            nn.LeakyReLU(0.2),
        )

        self.fc = nn.Sequential(
            nn.Linear(256, 32),
            nn.LeakyReLU(0.2),
#             nn.Linear(64, 32),
#             nn.LeakyReLU(0.2),
#             nn.Linear(32, 16),
#             nn.LeakyReLU(0.2),
#             nn.Linear(16, 8),
#             nn.LeakyReLU(0.2),
            nn.Linear(32, 1)
        )

    def forward(self, x):
        out = self.conv(x)
        out = nn.Flatten()(out)
        out = self.fc(out)

        return out
```

In [12]:

```
class Generator(nn.Module):

    def __init__(self):

        super(Generator, self).__init__()

        self.conv = nn.Sequential(
            nn.Upsample(scale_factor=2, mode='bilinear', align_corners=False),
            nn.Conv2d(in_channels=dim_latent, out_channels=128, kernel_size=3, s
tride=1, padding=1, bias=True),
            nn.BatchNorm2d(128),
            nn.LeakyReLU(0.2),

            nn.Upsample(scale_factor=2, mode='bilinear', align_corners=False),
            nn.Conv2d(in_channels=128, out_channels=64, kernel_size=3, stride=1,
padding=1, bias=True),
            nn.BatchNorm2d(64),
            nn.LeakyReLU(0.2),

            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.BatchNorm2d(32),
            nn.LeakyReLU(0.2),

            nn.Upsample(scale_factor=2, mode='bilinear', align_corners=False),
            nn.Conv2d(in_channels=32, out_channels=16, kernel_size=3, stride=1,
padding=1, bias=True),
            nn.BatchNorm2d(16),
            nn.LeakyReLU(0.2),

            nn.Upsample(scale_factor=2, mode='bilinear', align_corners=False),
            nn.Conv2d(in_channels=16, out_channels=1, kernel_size=3, stride=1, p
adding=1, bias=True),

            nn.Sigmoid()
        )

    def forward(self, x):

        out = self.conv(x)

        return out
```

build network

In [13]:

```
def weights_init(m):
    classname = m.__class__.__name__
    if classname.find("Conv") != -1:
        nn.init.xavier_uniform_(m.weight)
        nn.init.constant_(m.bias, 1.)
    elif classname.find("BatchNorm") != -1:
        nn.init.constant_(m.weight, 1.)
        nn.init.constant_(m.bias, 1.)
    elif classname.find("Linear") != -1:
        nn.init.xavier_uniform_(m.weight)
        nn.init.constant_(m.bias, 1.)
```

In [14]:

```
generator       = Generator().to(device)
discriminator   = Discriminator().to(device)

generator = generator.apply(weights_init)
discriminator = discriminator.apply(weights_init)

optimizer_generator = torch.optim.Adam(generator.parameters(), lr=0.001, betas=
(0.5, 0.999))
optimizer_discriminator = torch.optim.Adam(discriminator.parameters(), lr=0.001,
betas=(0.5, 0.999))
```

compute the prediction

In [15]:

```
def compute_prediction(model, input):

    prediction = model(input)

    return prediction
```

compute the accuracy

In [16]:

```
def compute_bounding_mask(prediction_binary):

    bounding_mask = torch.zeros_like(prediction_binary)

    for i in range(prediction_binary.shape[0]):
        prediction = prediction_binary[i]
        (idx_row, idx_col) = torch.nonzero(prediction, as_tuple=True)

        if len(idx_row) > 0:
            idx_row_min = idx_row.min()
            idx_row_max = idx_row.max()

            idx_col_min = idx_col.min()
            idx_col_max = idx_col.max()

            bounding_mask[i, idx_row_min:idx_row_max+1, idx_col_min:idx_col_max+
1] = 1

    return bounding_mask
```

In [17]:

```
def compute_accuracy(prediction):

    binary       = (prediction >= 0.5)
    mask         = compute_bounding_mask(binary)

    intersection = (binary & mask).float().sum((1, 2))
    union         = (binary | mask).float().sum((1, 2))

    eps          = 1e-8
    correct      = (intersection + eps) / (union + eps)
    accuracy     = correct.mean() * 100.0
    accuracy     = accuracy.cpu()

    return accuracy
```

train

In [18]:

```
def train(generator, discriminator, dataloader):

    loss_generator_epoch = []
    loss_discriminator_epoch = []

    for index_batch, (real) in enumerate(dataloader):
        real         = real.to(device)
        size_batch   = len(real)
        latent       = torch.randn(size_batch, dim_latent, device=device)
        latent       = torch.reshape(latent, [size_batch, dim_latent, 1, 1])

        # ----------------------------------------------------------------------
-----
        #
        # update the generator
        #
        # ----------------------------------------------------------------------
-----
        generator.train()
        discriminator.eval()

        optimizer_generator.zero_grad()
        fake = compute_prediction(generator, latent)
        prediction_fake = compute_prediction(discriminator, fake)
        label_fake = torch.ones_like(prediction_fake)
        loss_label = nn.BCEWithLogitsLoss()(prediction_fake, label_fake)
        loss_generator = loss_label
        loss_generator.backward()
        optimizer_generator.step()

        # ----------------------------------------------------------------------
-----
        #
        # update the discriminator
        #
        # ----------------------------------------------------------------------
-----
        generator.eval()
        discriminator.train()

        optimizer_discriminator.zero_grad()
        fake = compute_prediction(generator, latent)
        prediction_real = compute_prediction(discriminator, real)
        prediction_fake = compute_prediction(discriminator, fake)
        loss_real = nn.BCEWithLogitsLoss()(prediction_real, torch.ones_like(pred
iction_real, device=device))
        loss_fake = nn.BCEWithLogitsLoss()(prediction_fake, torch.zeros_like(pre
diction_fake, device=device))
        loss_discriminator = (loss_real + loss_fake) / 2.
        loss_discriminator.backward()
        optimizer_discriminator.step()

        loss_generator_epoch.append(loss_generator.item())
        loss_discriminator_epoch.append(loss_discriminator.item())

    return np.mean(loss_generator_epoch), np.mean(loss_discriminator_epoch)
```

test

In [19]:

```
def test(generator, latent):

    generator.eval()

    prediction  = generator(latent)
    prediction  = prediction.squeeze(axis=1)
    accuracy    = compute_accuracy(prediction)

    return accuracy
```

training epoch

In [20]:

```
number_epoch     = 2000
accuracy_epoch   = np.zeros(number_epoch)
loss_generator = np.zeros(number_epoch)
loss_discriminator = np.zeros(number_epoch)

num_latent_test = 100
latent_test = torch.randn(num_latent_test, dim_latent, device=device)
latent_test = torch.reshape(latent_test, [num_latent_test, dim_latent, 1, 1])

for i in range(number_epoch):
    loss_generator_epoch, loss_discriminator_epoch = train(generator, discrimina
tor, dataloader_real)
    accuracy = test(generator, latent_test)
    accuracy_epoch[i] = accuracy

    loss_generator[i] = loss_generator_epoch
    loss_discriminator[i] = loss_discriminator_epoch
    print(f'epoch {i}, loss_generator = {loss_generator_epoch}, loss_discriminat
or={loss_discriminator_epoch}, accuracy={accuracy}')

    # if accuracy>98 stop
    if i>10 and accuracy>98:
        accuracy_epoch = accuracy_epoch[:i+1]
        break
```

```
epoch 0, loss_generator = 0.8082629900839594, loss_discriminator=0.7
643318666352166, accuracy=84.20942687988281
epoch 1, loss_generator = 0.7027878527288084, loss_discriminator=0.6
972652969536958, accuracy=87.51338958740234
epoch 2, loss_generator = 0.7522311550599557, loss_discriminator=0.7
334282446790624, accuracy=91.7977294921875
epoch 3, loss_generator = 0.6983382472285518, loss_discriminator=0.6
929080552524991, accuracy=90.97225189208984
epoch 4, loss_generator = 0.6983237134085761, loss_discriminator=0.6
935412967646564, accuracy=92.1667251586914
epoch 5, loss_generator = 0.7589374214962676, loss_discriminator=0.7
358458081881205, accuracy=100.0
epoch 6, loss_generator = 0.6913192913488105, loss_discriminator=0.6
869762160159923, accuracy=89.08001708984375
epoch 7, loss_generator = 0.9522485311660501, loss_discriminator=0.6
915906588236491, accuracy=93.10673522949219
epoch 8, loss_generator = 1.1243618664918122, loss_discriminator=0.5
409262560032032, accuracy=80.57636260986328
epoch 9, loss_generator = 1.3604767507976956, loss_discriminator=0.4
761901090542475, accuracy=76.34229278564453
epoch 10, loss_generator = 1.3620896498362223, loss_discriminator=0.
474625191644386, accuracy=77.29827117919922
epoch 11, loss_generator = 1.5573338956744582, loss_discriminator=0.
4249078617051796, accuracy=81.41233825683594
epoch 12, loss_generator = 1.7527882244851853, loss_discriminator=0.
3811194009251065, accuracy=76.98038482666016
epoch 13, loss_generator = 1.960030887303529, loss_discriminator=0.3
5012611548105876, accuracy=78.46669006347656
epoch 14, loss_generator = 2.273727814356486, loss_discriminator=0.2
787886160943243, accuracy=80.28314971923828
epoch 15, loss_generator = 2.4653858259872155, loss_discriminator=0.
29219485813820806, accuracy=81.42350006103516
epoch 16, loss_generator = 3.0391117316705207, loss_discriminator=0.
20908179531494778, accuracy=82.75890350341797
epoch 17, loss_generator = 3.580859975461607, loss_discriminator=0.1
7330280393362046, accuracy=84.18598937988281
epoch 18, loss_generator = 3.7706255082730893, loss_discriminator=0.
15167678067529644, accuracy=83.10103607177734
epoch 19, loss_generator = 4.622254577389469, loss_discriminator=0.1
2233960833400488, accuracy=85.0777359008789
epoch 20, loss_generator = 4.426264007003219, loss_discriminator=0.1
2268856842484739, accuracy=84.14549255371094
epoch 21, loss_generator = 5.024055301922339, loss_discriminator=0.1
3281221559478176, accuracy=87.44444274902344
epoch 22, loss_generator = 4.31471023912783, loss_discriminator=0.18
808373814379728, accuracy=87.71733093261719
epoch 23, loss_generator = 4.307887722386254, loss_discriminator=0.1
9419753308649415, accuracy=87.39325714111328
epoch 24, loss_generator = 4.003738592289112, loss_discriminator=0.2
3217686889348207, accuracy=82.76016998291016
epoch 25, loss_generator = 3.4664252936840056, loss_discriminator=0.
24246207078297932, accuracy=88.41580200195312
epoch 26, loss_generator = 3.649142809708913, loss_discriminator=0.2
4145819340591076, accuracy=89.46354675292969
epoch 27, loss_generator = 3.585045764181349, loss_discriminator=0.2
379020240019869, accuracy=89.93412017822266
epoch 28, loss_generator = 3.9421526149467185, loss_discriminator=0.
19966096276486361, accuracy=89.08478546142578
epoch 29, loss_generator = 3.8899481417956174, loss_discriminator=0.
```

```
24355100558863746, accuracy=91.60093688964844
epoch 30, loss_generator = 3.9328899423281354, loss_discriminator=0.
2145877868488983, accuracy=86.38325500488281
epoch 31, loss_generator = 4.266624908756326, loss_discriminator=0.2
3212754037921077, accuracy=85.96870422363281
epoch 32, loss_generator = 3.3968014997464637, loss_discriminator=0.
3183640140074271, accuracy=87.832763671875
epoch 33, loss_generator = 4.094814695252312, loss_discriminator=0.2
476238193611304, accuracy=91.5387954711914
epoch 34, loss_generator = 4.4703655852211845, loss_discriminator=0.
21463038879964086, accuracy=92.55770111083984
epoch 35, loss_generator = 4.263258313028901, loss_discriminator=0.2
3003059148236557, accuracy=90.92512512207031
epoch 36, loss_generator = 5.015959831520363, loss_discriminator=0.1
8908967309527927, accuracy=91.64525604248047
epoch 37, loss_generator = 5.68901817533705, loss_discriminator=0.16
798959203340388, accuracy=90.32850646972656
epoch 38, loss_generator = 6.077758192133021, loss_discriminator=0.1
6120823980481536, accuracy=91.03966522216797
epoch 39, loss_generator = 5.553621039567171, loss_discriminator=0.1
7233437316285238, accuracy=90.04877471923828
epoch 40, loss_generator = 4.9196132456814805, loss_discriminator=0.
1660916232124523, accuracy=88.65951538085938
epoch 41, loss_generator = 4.924588997275741, loss_discriminator=0.1
9302286279422265, accuracy=89.90026092529297
epoch 42, loss_generator = 4.635873254140218, loss_discriminator=0.1
8597089537867792, accuracy=91.55152130126953
epoch 43, loss_generator = 4.7808431263875075, loss_discriminator=0.
2811540625161595, accuracy=90.78208923339844
epoch 44, loss_generator = 3.728647326540064, loss_discriminator=0.2
914534136101052, accuracy=90.42366790771484
epoch 45, loss_generator = 4.289696999170162, loss_discriminator=0.2
782743180239642, accuracy=91.83181762695312
epoch 46, loss_generator = 4.804126509472176, loss_discriminator=0.2
2151669672241917, accuracy=91.35775756835938
epoch 47, loss_generator = 4.353231819470723, loss_discriminator=0.2
963639687332842, accuracy=92.21605682373047
epoch 48, loss_generator = 5.590406799316407, loss_discriminator=0.1
981130360453217, accuracy=89.69986724853516
epoch 49, loss_generator = 5.27590650540811, loss_discriminator=0.21
120277803253246, accuracy=92.37712097167969
epoch 50, loss_generator = 5.833990669250488, loss_discriminator=0.1
79158312689375, accuracy=93.57933044433594
epoch 51, loss_generator = 3.155111863160575, loss_discriminator=0.3
649993650891163, accuracy=92.63752746582031
epoch 52, loss_generator = 3.0244055911346717, loss_discriminator=0.
31205638729863694, accuracy=92.34168243408203
epoch 53, loss_generator = 5.279647572614529, loss_discriminator=0.2
300964398516549, accuracy=91.22415161132812
epoch 54, loss_generator = 5.565741634810412, loss_discriminator=0.2
2188065703268403, accuracy=92.83433532714844
epoch 55, loss_generator = 5.2192006691738415, loss_discriminator=0.
2503238366709815, accuracy=91.41524505615234
epoch 56, loss_generator = 5.930626337616532, loss_discriminator=0.2
011133623343927, accuracy=91.63658142089844
epoch 57, loss_generator = 6.2713178407262875, loss_discriminator=0.
2225825733884617, accuracy=92.82865905761719
epoch 58, loss_generator = 5.032997703552246, loss_discriminator=0.2
6264107718511864, accuracy=91.29759979248047
```

```
epoch 59, loss_generator = 6.137228870391846, loss_discriminator=0.2
047358697211301, accuracy=90.33395385742188
epoch 60, loss_generator = 6.218489473837393, loss_discriminator=0.1
9614289689947056, accuracy=90.59857177734375
epoch 61, loss_generator = 5.963494848321985, loss_discriminator=0.2
0990066448295558, accuracy=90.28412628173828
epoch 62, loss_generator = 6.02463938748395, loss_discriminator=0.16
730702530454705, accuracy=92.13375091552734
epoch 63, loss_generator = 5.801383698428118, loss_discriminator=0.1
7522610006509004, accuracy=93.39067077636719
epoch 64, loss_generator = 5.856387018274378, loss_discriminator=0.1
4415361299007026, accuracy=91.99081420898438
epoch 65, loss_generator = 5.34918668711627, loss_discriminator=0.15
64818392197291, accuracy=93.04478454589844
epoch 66, loss_generator = 5.329869121975369, loss_discriminator=0.1
614993942556558, accuracy=91.05958557128906
epoch 67, loss_generator = 5.037941749007613, loss_discriminator=0.1
7389597372600327, accuracy=92.12467193603516
epoch 68, loss_generator = 5.211588804810136, loss_discriminator=0.1
6734876577500943, accuracy=94.98899841308594
epoch 69, loss_generator = 3.6006228937043083, loss_discriminator=0.
3027732202300319, accuracy=92.1993637084961
epoch 70, loss_generator = 4.557053037926003, loss_discriminator=0.2
173115169008573, accuracy=91.87950134277344
epoch 71, loss_generator = 4.818367957185816, loss_discriminator=0.2
548279994063907, accuracy=91.03377532958984
epoch 72, loss_generator = 5.621056161103425, loss_discriminator=0.2
550302648985827, accuracy=93.7872085571289
epoch 73, loss_generator = 5.623464893411707, loss_discriminator=0.2
4457846929629642, accuracy=90.66010284423828
epoch 74, loss_generator = 5.483881175959552, loss_discriminator=0.2
4715743285638314, accuracy=89.63140869140625
epoch 75, loss_generator = 9.533017230916906, loss_discriminator=0.0
9703522027056251, accuracy=81.46532440185547
epoch 76, loss_generator = 7.446395310649166, loss_discriminator=0.1
6692125524083773, accuracy=92.42424011230469
epoch 77, loss_generator = 6.684698507520888, loss_discriminator=0.1
9940119280859275, accuracy=90.4032974243164
epoch 78, loss_generator = 5.672221038959645, loss_discriminator=0.2
2358151420398995, accuracy=90.1744384765625
epoch 79, loss_generator = 5.9573861863878035, loss_discriminator=0.
19885778973499935, accuracy=92.44161224365234
epoch 80, loss_generator = 5.484625477261013, loss_discriminator=0.2
3409820270759088, accuracy=91.92988586425781
epoch 81, loss_generator = 6.105573742477982, loss_discriminator=0.1
9224909612977947, accuracy=91.90402221679688
epoch 82, loss_generator = 7.325678240811383, loss_discriminator=0.1
552903743253814, accuracy=92.7491455078125
epoch 83, loss_generator = 5.024997290417, loss_discriminator=0.2188
1565617190468, accuracy=92.99227142333984
epoch 84, loss_generator = 5.635455205705431, loss_discriminator=0.1
818334893495948, accuracy=91.79354858398438
epoch 85, loss_generator = 5.889366103984692, loss_discriminator=0.1
7044834858841365, accuracy=93.52947998046875
epoch 86, loss_generator = 5.585920856617115, loss_discriminator=0.1
8281907226752353, accuracy=92.6313247680664
epoch 87, loss_generator = 5.721853271237126, loss_discriminator=0.2
0001092503468196, accuracy=91.81695556640625
epoch 88, loss_generator = 5.315864877789108, loss_discriminator=0.2
```

```
3878052565786573, accuracy=91.72125244140625
epoch 89, loss_generator = 6.284599477273447, loss_discriminator=0.2
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epoch 430, loss_generator = 8.732350527798689, loss_discriminator=0.
11077650403948845, accuracy=96.54327392578125
epoch 431, loss_generator = 8.207335502130015, loss_discriminator=0.
11611758425003953, accuracy=96.72345733642578
epoch 432, loss_generator = 8.470511750821714, loss_discriminator=0.
11458271630108356, accuracy=96.59849548339844
epoch 433, loss_generator = 9.404518692581743, loss_discriminator=0.
10621802311528612, accuracy=96.65312957763672
epoch 434, loss_generator = 8.632697886007804, loss_discriminator=0.
11494878363554124, accuracy=96.7145767211914
epoch 435, loss_generator = 9.05750480581213, loss_discriminator=0.1
2631638975882972, accuracy=96.65581512451172
epoch 436, loss_generator = 9.234907174993443, loss_discriminator=0.
11981539982888434, accuracy=95.6423110961914
epoch 437, loss_generator = 9.45547728008694, loss_discriminator=0.1
084246199440073, accuracy=96.67656707763672
epoch 438, loss_generator = 10.605786644970928, loss_discriminator=
0.10255656856353636, accuracy=96.56919860839844
epoch 439, loss_generator = 10.430407467594852, loss_discriminator=
0.09958719935406138, accuracy=96.66259002685547
epoch 440, loss_generator = 8.49193620858369, loss_discriminator=0.1
0700371011539742, accuracy=97.63046264648438
epoch 441, loss_generator = 8.707506003203216, loss_discriminator=0.
09962157871988085, accuracy=96.463134765625
epoch 442, loss_generator = 8.22848542884544, loss_discriminator=0.0
```

```
9357521358739447, accuracy=96.66783905029297
epoch 443, loss_generator = 8.06623924749869, loss_discriminator=0.0
9965895658565892, accuracy=95.5280990600586
epoch 444, loss_generator = 8.720835777565284, loss_discriminator=0.
10143446060656397, accuracy=96.80402374267578
epoch 445, loss_generator = 9.26607496296918, loss_discriminator=0.0
9536481177503311, accuracy=95.65274810791016
epoch 446, loss_generator = 8.831186072031658, loss_discriminator=0.
08059510329255351, accuracy=97.14743041992188
epoch 447, loss_generator = 8.302925233487729, loss_discriminator=0.
0790676589089411 3, accuracy=97.15553283691406
epoch 448, loss_generator = 7.351055060492621, loss_discriminator=0.
0912532354739529, accuracy=96.93804931640625
epoch 449, loss_generator = 7.571500262507686, loss_discriminator=0.
0733762727153522, accuracy=97.4209976196289
epoch 450, loss_generator = 8.232349621808087, loss_discriminator=0.
07115782224055793, accuracy=96.664794921875
epoch 451, loss_generator = 7.89321002430386, loss_discriminator=0.0
7739289608542566, accuracy=97.15860748291016
epoch 452, loss_generator = 7.676506793057477, loss_discriminator=0.
08204296540330958, accuracy=97.41244506835938
epoch 453, loss_generator = 7.24060208355939, loss_discriminator=0.0
8605912666491888, accuracy=96.89875793457031
epoch 454, loss_generator = 7.181978578920718, loss_discriminator=0.
0832837748237782, accuracy=96.98011016845703
epoch 455, loss_generator = 7.378570055078577, loss_discriminator=0.
07867942597992994, accuracy=97.68498229980469
epoch 456, loss_generator = 7.132302446718569, loss_discriminator=0.
0719336797448772, accuracy=97.19715881347656
epoch 457, loss_generator = 6.872718079884847, loss_discriminator=0.
07589828855340817, accuracy=96.20040893554688
epoch 458, loss_generator = 7.2190486166212295, loss_discriminator=
0.07028240280363847, accuracy=97.955810546875
epoch 459, loss_generator = 7.206185837145205, loss_discriminator=0.
07257438414833611, accuracy=96.6709976196289
epoch 460, loss_generator = 6.5808637901588725, loss_discriminator=
0.07250777750655457, accuracy=97.5972900390625
epoch 461, loss_generator = 7.257132754502473, loss_discriminator=0.
07622050230080883, accuracy=97.06265258789062
epoch 462, loss_generator = 7.371435115955494, loss_discriminator=0.
06951218930038588, accuracy=97.70030975341797
epoch 463, loss_generator = 7.22562922724971, loss_discriminator=0.0
683253218350863, accuracy=97.66573333740234
epoch 464, loss_generator = 6.889823698114466, loss_discriminator=0.
06356216711509559, accuracy=97.81315612792969
epoch 465, loss_generator = 6.860033349637632, loss_discriminator=0.
05819869101633904 5, accuracy=97.22891235351562
epoch 466, loss_generator = 6.594887260154442, loss_discriminator=0.
05694353420252877 6, accuracy=97.06239318847656
epoch 467, loss_generator = 6.656566434436375, loss_discriminator=0.
05548320973498954, accuracy=97.46192932128906
epoch 468, loss_generator = 5.94052049142343, loss_discriminator=0.0
5712720895772455, accuracy=97.1368637084961
epoch 469, loss_generator = 5.947152160715174, loss_discriminator=0.
0660790933503045, accuracy=98.07032012939453
```

functions for presenting the results

In [21]:

```
def function_result_01():

    num_latent_visualize = 16

    latent_visualize = torch.randn(num_latent_visualize, dim_latent, device=devi
ce)
    latent_visualize = torch.reshape(latent_visualize, [num_latent_visualize, di
m_latent, 1, 1])

    prediction = compute_prediction(generator, latent_visualize)
    prediction = prediction.squeeze(axis=1)
    prediction_binary = (prediction >= 0.5)
    bounding_mask = compute_bounding_mask(prediction_binary)

    fake = prediction.detach().cpu()
    mask = bounding_mask.detach().cpu()

    nRow = 4
    nCol = 4
    size = 3

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

    for r in range(nRow):
        for c in range(nCol):
            k = c + r * nCol
            axes[r, c].imshow(fake[k], cmap='gray', vmin=0, vmax=1)
            axes[r, c].xaxis.set_visible(False)
            axes[r, c].yaxis.set_visible(False)

    plt.tight_layout()
    plt.show()

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

    for r in range(nRow):
        for c in range(nCol):
            k = c + r * nCol
            axes[r, c].imshow(mask[k], cmap='gray', vmin=0, vmax=1)
            axes[r, c].xaxis.set_visible(False)
            axes[r, c].yaxis.set_visible(False)

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

In [22]:

```
def function_result_02():

    title           = 'accuracy'
    label_axis_x    = 'epoch'
    label_axis_y    = 'accuracy'

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

    plt.plot(accuracy_epoch)

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

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

In [23]:

```
def function_result_03():

    print('final accuracy = %9.8f' % (accuracy_epoch[-1]))
```

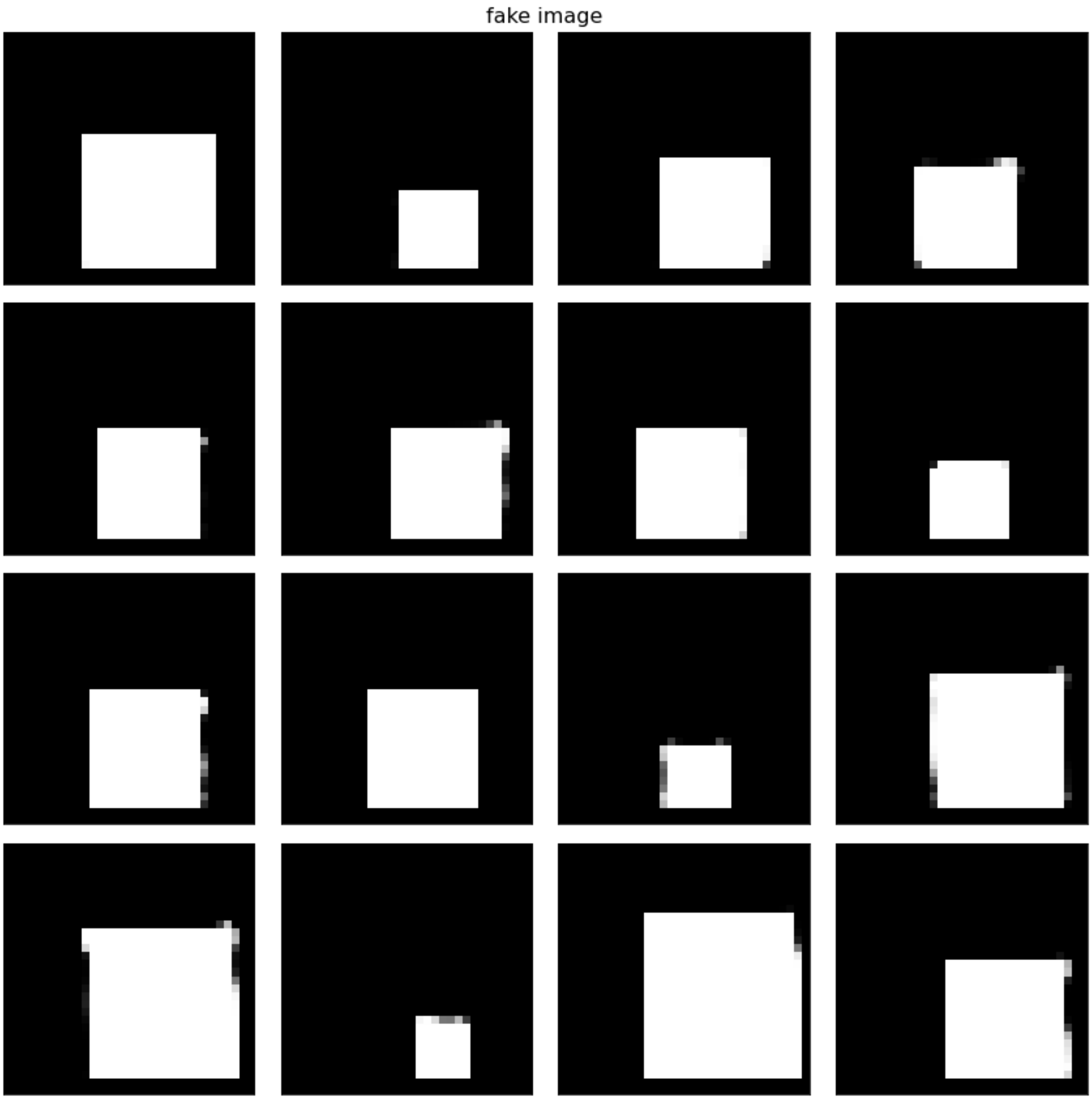
---

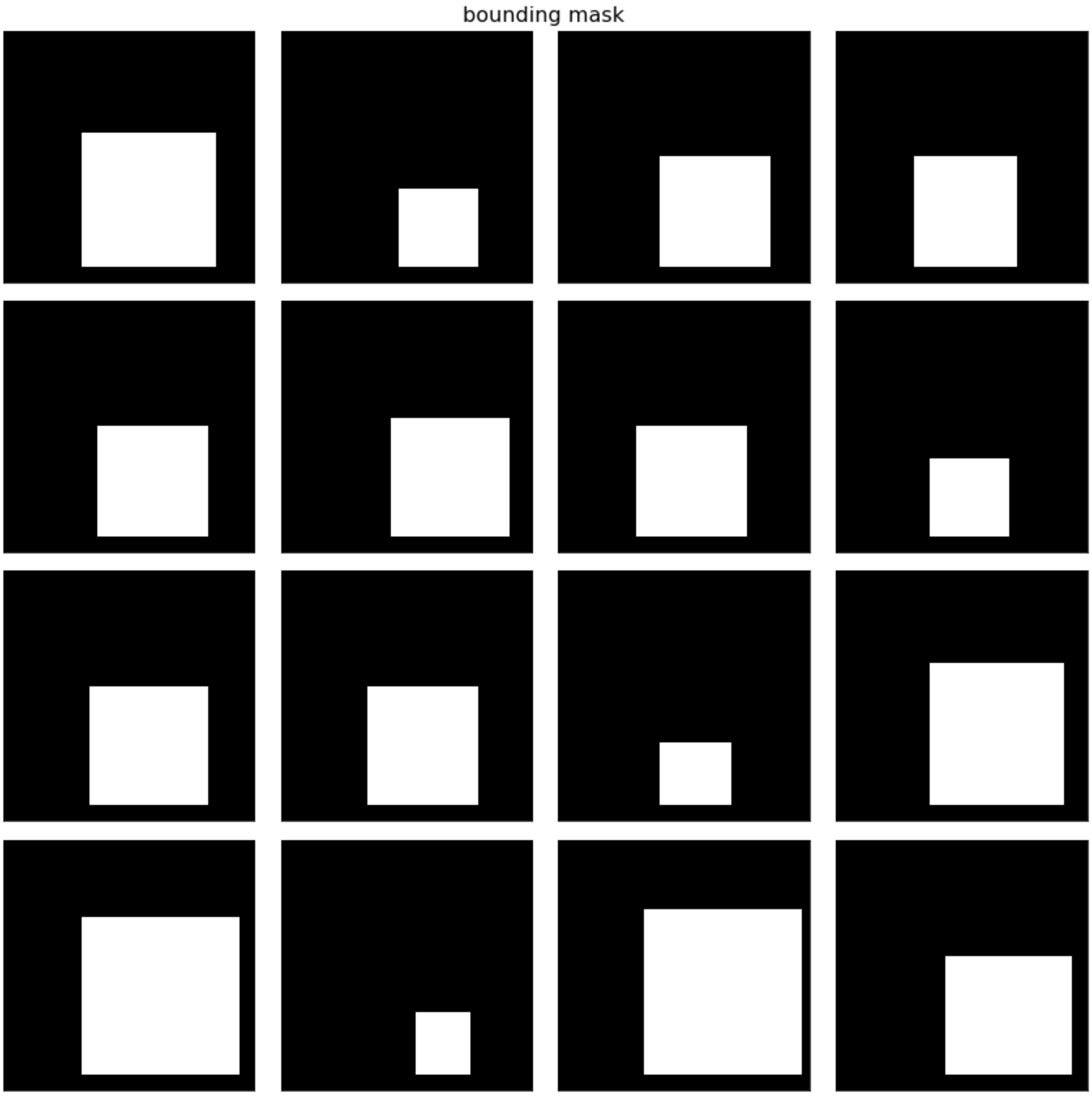
results

In [24]:

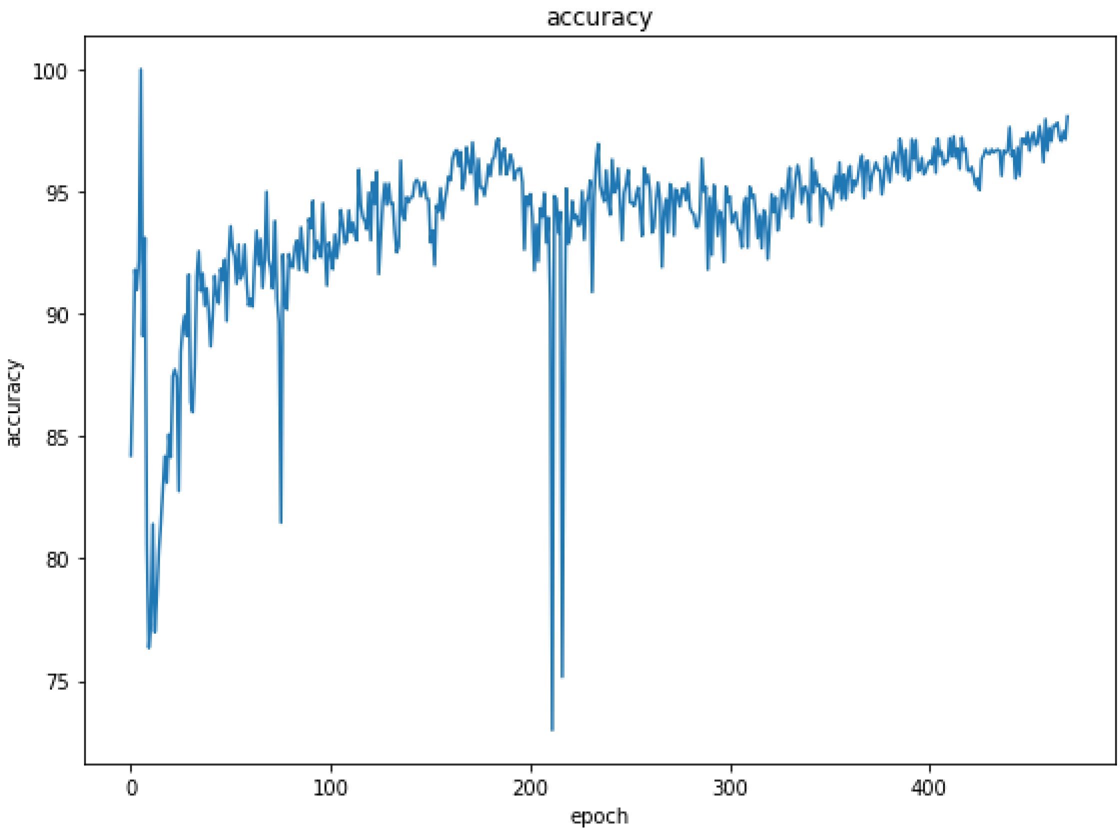
```
number_result = 3

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
#
##########################################################################
```




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

final accuracy = 98.07032013
```

In [ ]: