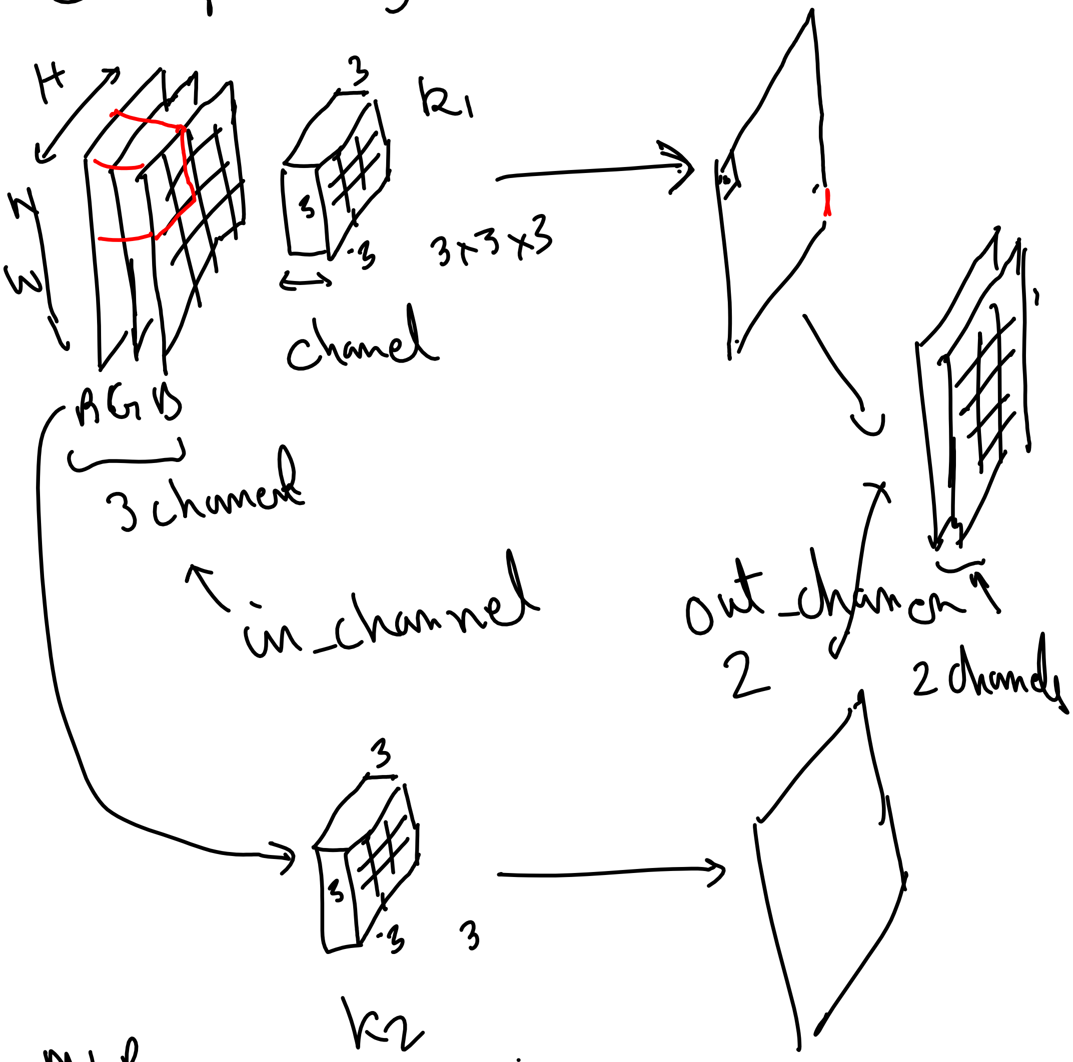
① Logging and plotting

tensorboard

② Checkpointing

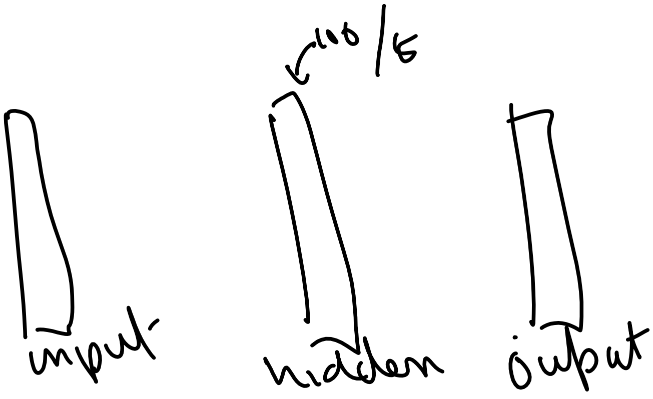
Save your weights
every few iteration

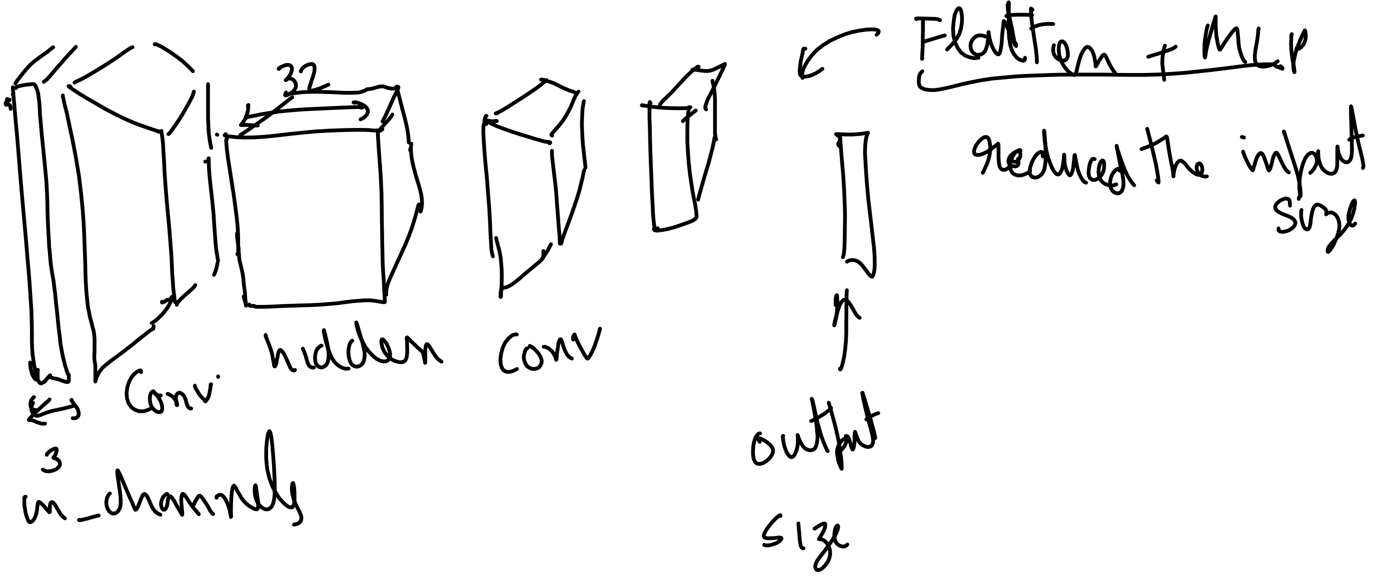
③ Preprocessing

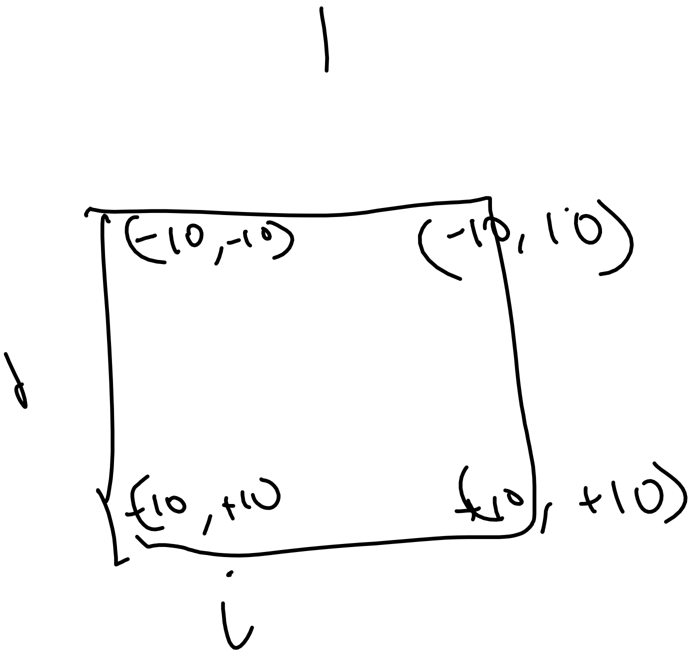


MLP

Linear







Fully
Convolution

$$\underline{p}^T \underline{k} = |\underline{p}||\underline{k}| \cos(\theta)$$

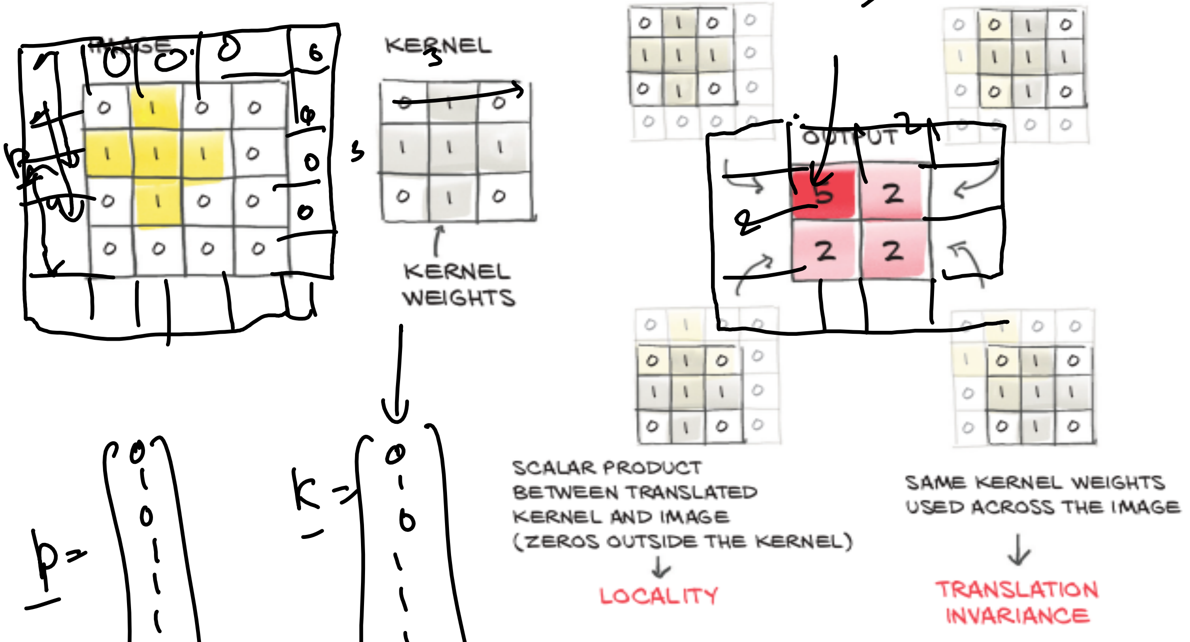
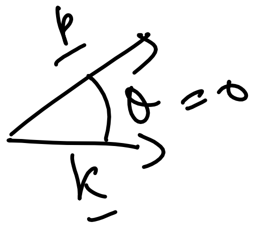


IMAGE
KERNEL
3
KERNEL WEIGHTS
OUTPUT
5
2
2
2
SCALAR PRODUCT BETWEEN TRANSLATED KERNEL AND IMAGE (ZEROS OUTSIDE THE KERNEL)
LOCALITY
SAME KERNEL WEIGHTS USED ACROSS THE IMAGE
TRANSLATION INVARIANCE



$$\underline{p} = \begin{bmatrix} 0 \\ 1 \\ 0 \\ 1 \\ 1 \\ 1 \\ 0 \\ 1 \\ 0 \end{bmatrix} \qquad \underline{k} = \begin{bmatrix} 0 \\ 1 \\ 0 \\ 1 \\ 1 \\ 1 \\ 0 \\ 1 \\ 0 \end{bmatrix}_{9\times1}$$

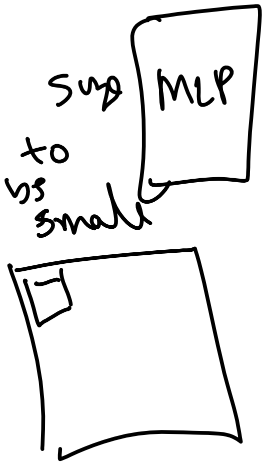
$\underline{p} \propto \underline{k}$

then

$\underline{p}^T \underline{k}$

is max

$$32 \times 32 \to \text{Conv } 3\times3 \longrightarrow 32 \times 32 \approx$$



$\underline{p} \propto \underline{k}$

or $\underline{p} \propto -\underline{k}$

the $|\underline{p}^T \underline{k}|$ is max

Pooling layers

are used to reduce the

size of intermediate

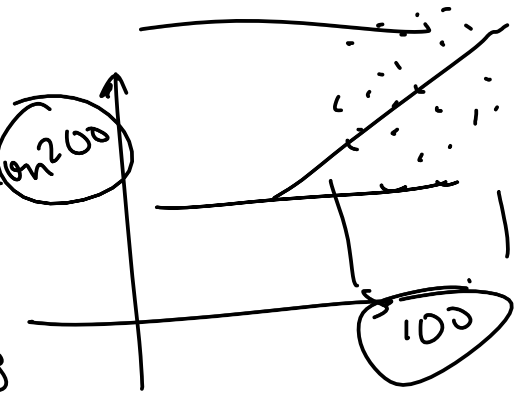
"images"

<u>Maxpooling</u> <u>Avgpooling</u>

(3) Preprocessing

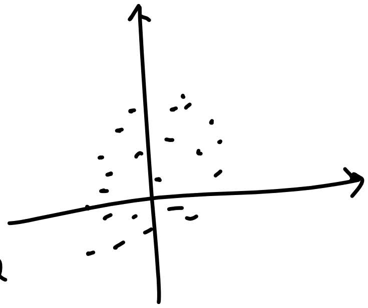
↳ Initialization

Prob ↳ { Vanishing or explodin ging gradients



Sol Normalization

to zero mean unit variance

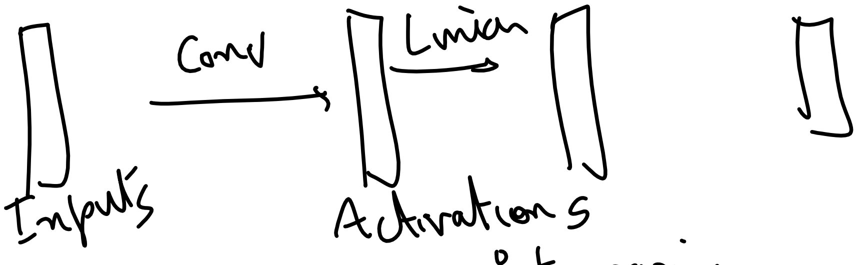


zero mean color unit variance

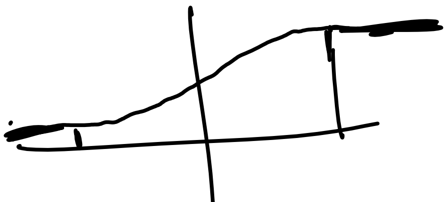
$$\underline{m} = \frac{1}{N_T} \sum_i I_i$$

$$\underline{v} = \sqrt{\frac{1}{(N_T-1)} \sum_i (\underline{I}_i - \underline{m})^2}$$

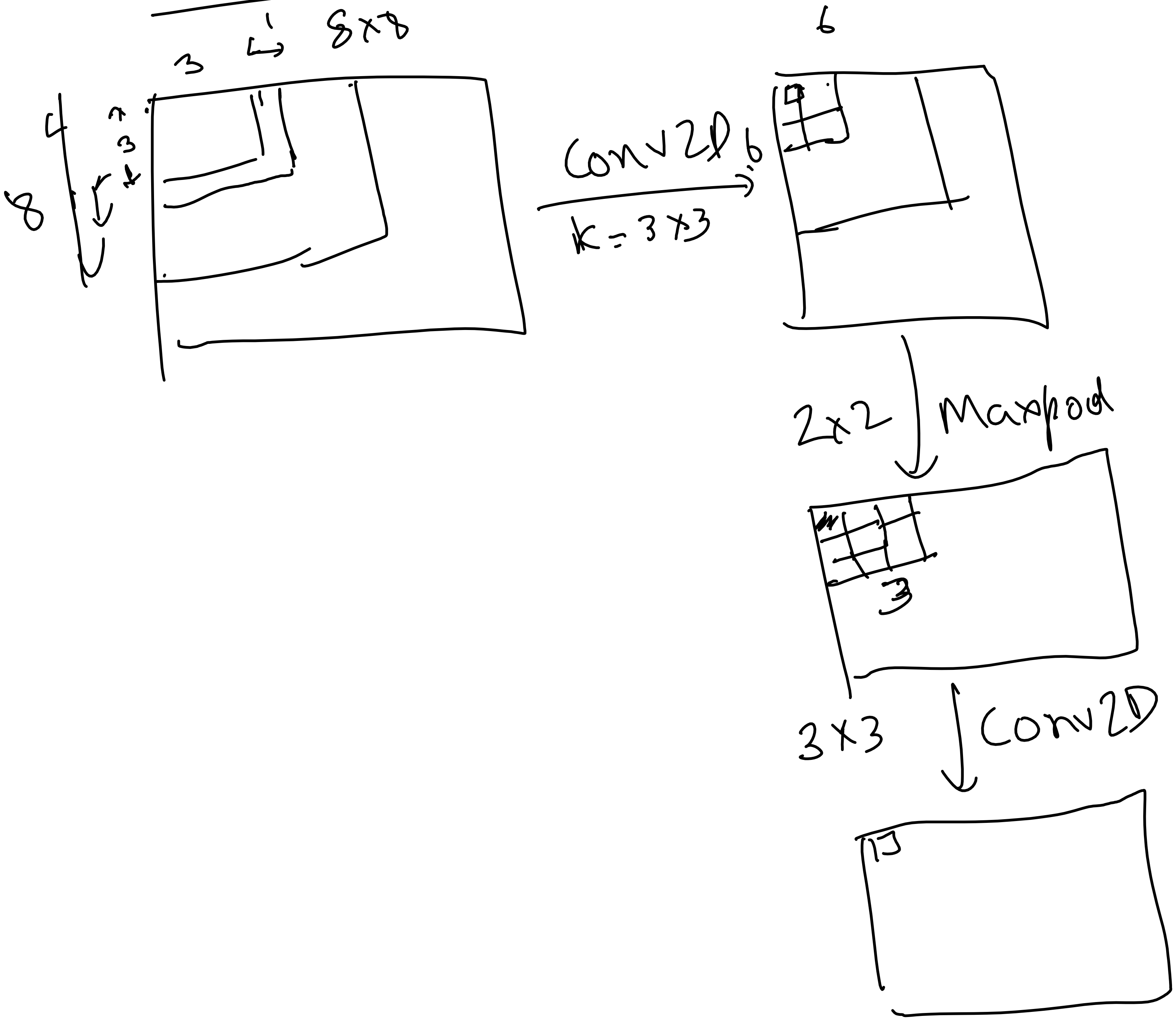
$$\tilde{\underline{I}}_i = (\underline{I}_i - \underline{m}) / \underline{v},$$



∼ unit variance



Field of View



In [ ]:

```python
# Adapted from: Chapter 7 and 8 of Deep Learning with Pytorch by Eli Stevens
try:
    import torch as t
    import torch.nn as tnn
except ImportError:
    print("Colab users: pytorch comes preinstalled. Select Change Ru")
    print("Local users: Please install pytorch for your hardware using instr
    print("ACG users: Please follow instructions here: https://vikasdhiman.i

    raise

if t.cuda.is_available():
    DEVICE="cuda"
elif t.mps.is_available():
    DEVICE="mps"
else:
    DEVICE="cpu"

DTYPE = t.get_default_dtype()
```

In [ ]:

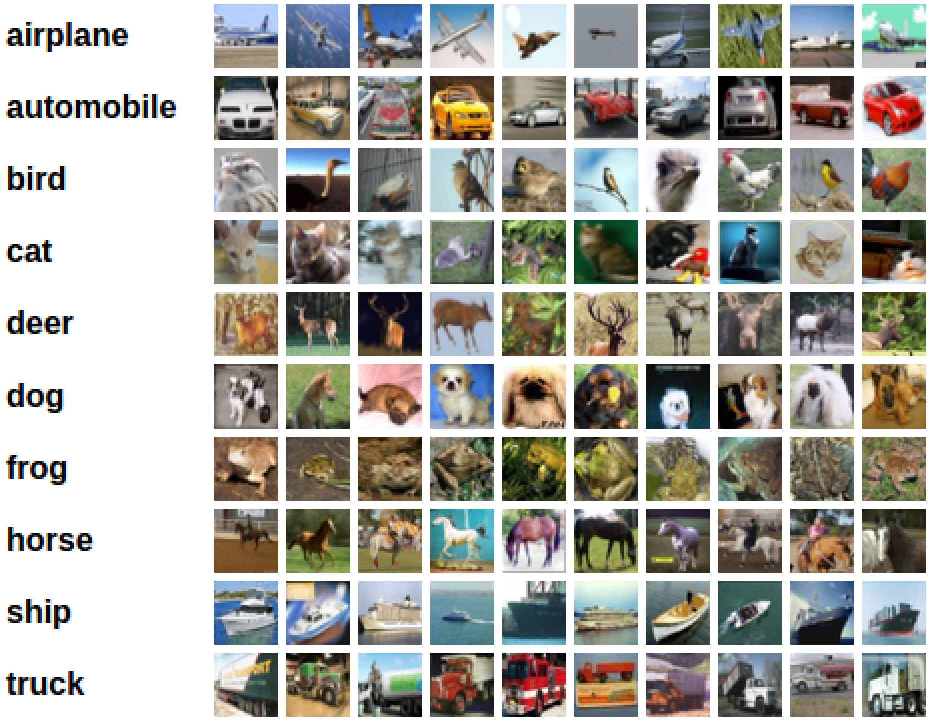
```python
## Doing it the Pytorch way without using our custom feature extraction

import torch
import torch.nn
import torch.optim
import torchvision
from torchvision.transforms import ToTensor, Compose, Normalize
from torch.utils.data import DataLoader

torch.manual_seed(17)
DATASET_MEAN = [0.4914, 0.4822, 0.4465]
DATASET_STD = [0.2470, 0.2435, 0.2616]
# Getting the dataset, the Pytorch way
all_training_data = torchvision.datasets.CIFAR10(
    root="data",
    train=True,
    download=True,
    transform=Compose([ToTensor(),
                       Normalize(DATASET_MEAN, # dataset mean
                                 DATASET_STD)]) # dataset std
)

test_data = torchvision.datasets.CIFAR10(
    root="data",
    train=False,
    download=True,
    transform=Compose([ToTensor(),
                       Normalize(DATASET_MEAN, # dataset mean
                                 DATASET_STD)]) # dataset std
)
```

```
Downloading https://www.cs.toronto.edu/~kriz/cifar-10-python.tar.gz to data/
cifar-10-python.tar.gz
100%|██████████| 170498071/170498071 [00:06<00:00, 27535441.22it/s]
```

```
Extracting data/cifar-10-python.tar.gz to data
Files already downloaded and verified
```

In [ ]:

```
training_data, validation_data = torch.utils.data.random_split(all_training_
```



In [ ]:

```
img, label = all_training_data[99]
img.shape, label
```

Out[ ]:

```
(torch.Size([3, 32, 32]), 1)
```

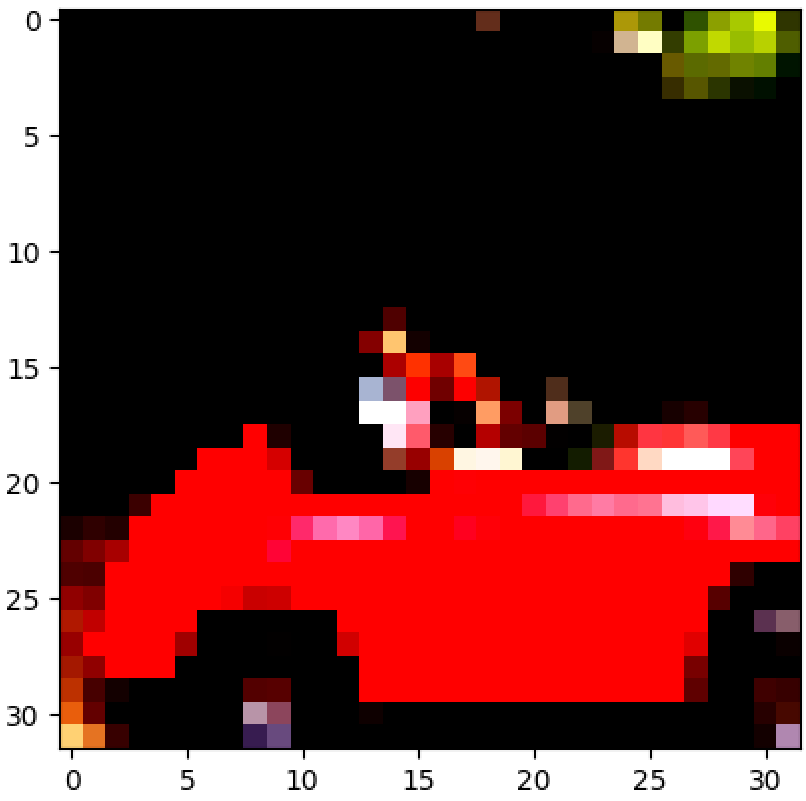
In [ ]:

```
import matplotlib.pyplot as plt
plt.imshow(img.permute(1, 2, 0))
```

```
WARNING:matplotlib.image:Clipping input data to the valid range for imshow w
ith RGB data ([0..1] for floats or [0..255] for integers).
```

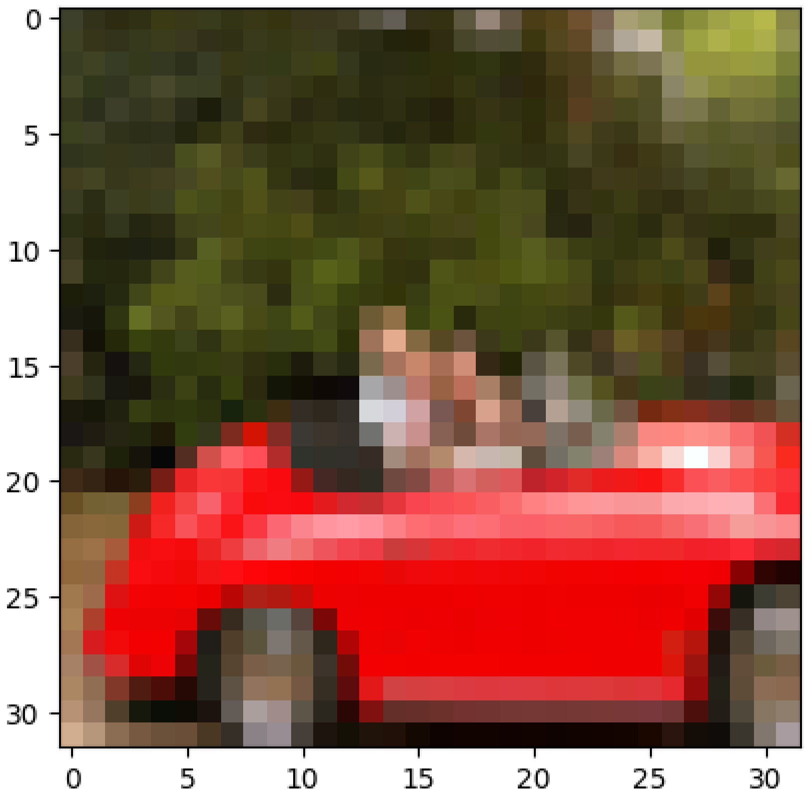
Out[ ]:

```
<matplotlib.image.AxesImage at 0x7feacb580850>
```



In [ ]:
```
plt.imshow((img.permute(1, 2, 0) *  torch.Tensor(DATASET_STD)
            +  torch.Tensor(DATASET_MEAN)))
```

Out[ ]:
```
<matplotlib.image.AxesImage at 0x7feac19ae8b0>
```



In [ ]:
```python
imgs = torch.stack([img_t for img_t, _ in all_training_data], dim=3)
imgs.reshape(3, -1).mean(dim=-1), imgs.reshape(3, -1).std(dim=-1)
```

Out[ ]:
```
(tensor([-1.2762e-06, -1.7074e-04,  1.1819e-04]),
 tensor([1.0001, 0.9999, 1.0000]))
```

In [ ]:
```python
import pickle
cifar_meta = pickle.load(open("data/cifar-10-batches-py/batches.meta", "rb")
class_names = [c.decode('utf-8') for c in cifar_meta[b'label_names']]
class_names
```

Out[ ]:
```
['airplane',
 'automobile',
 'bird',
 'cat',
 'deer',
 'dog',
 'frog',
 'horse',
 'ship',
 'truck']
```

In [ ]:
```python
# Hyper parameters
learning_rate = 1e-3 # controls how fast the gradient descent goes
batch_size = 64
epochs = 5
momentum = 0.9

training_dataloader = DataLoader(training_data, shuffle=True, batch_size=bat
validation_dataloader = DataLoader(validation_data,  batch_size=batch_size)
test_dataloader = DataLoader(test_data,  batch_size=batch_size)
X, y = next(iter(training_dataloader))
X.shape
```

Out[ ]:
```
torch.Size([64, 3, 32, 32])
```

In [ ]:
```
!pip install tensorboard
```

```
Looking in indexes: https://pypi.org/simple, https://us-python.pkg.dev/colab
-wheels/public/simple/
Requirement already satisfied: tensorboard in /usr/local/lib/python3.9/dist-
packages (2.12.1)
Requirement already satisfied: google-auth<3,>=1.6.3 in /usr/local/lib/pytho
n3.9/dist-packages (from tensorboard) (2.17.2)
Requirement already satisfied: protobuf>=3.19.6 in /usr/local/lib/python3.9/
dist-packages (from tensorboard) (3.20.3)
Requirement already satisfied: numpy>=1.12.0 in /usr/local/lib/python3.9/dis
t-packages (from tensorboard) (1.22.4)
Requirement already satisfied: tensorboard-plugin-wit>=1.6.0 in /usr/local/l
ib/python3.9/dist-packages (from tensorboard) (1.8.1)
Requirement already satisfied: requests<3,>=2.21.0 in /usr/local/lib/python
3.9/dist-packages (from tensorboard) (2.27.1)
Requirement already satisfied: markdown>=2.6.8 in /usr/local/lib/python3.9/d
ist-packages (from tensorboard) (3.4.3)
Requirement already satisfied: tensorboard-data-server<0.8.0,>=0.7.0 in /us
r/local/lib/python3.9/dist-packages (from tensorboard) (0.7.0)
Requirement already satisfied: absl-py>=0.4 in /usr/local/lib/python3.9/dist
-packages (from tensorboard) (1.4.0)
Requirement already satisfied: setuptools>=41.0.0 in /usr/local/lib/python3.
9/dist-packages (from tensorboard) (67.6.1)
Requirement already satisfied: werkzeug>=1.0.1 in /usr/local/lib/python3.9/d
ist-packages (from tensorboard) (2.2.3)
Requirement already satisfied: google-auth-oauthlib<1.1,>=0.5 in /usr/local/
lib/python3.9/dist-packages (from tensorboard) (1.0.0)
Requirement already satisfied: wheel>=0.26 in /usr/local/lib/python3.9/dist-
packages (from tensorboard) (0.40.0)
Requirement already satisfied: grpcio>=1.48.2 in /usr/local/lib/python3.9/di
st-packages (from tensorboard) (1.53.0)
Requirement already satisfied: rsa<5,>=3.1.4 in /usr/local/lib/python3.9/dis
t-packages (from google-auth<3,>=1.6.3->tensorboard) (4.9)
Requirement already satisfied: pyasn1-modules>=0.2.1 in /usr/local/lib/pytho
n3.9/dist-packages (from google-auth<3,>=1.6.3->tensorboard) (0.2.8)
Requirement already satisfied: six>=1.9.0 in /usr/local/lib/python3.9/dist-p
ackages (from google-auth<3,>=1.6.3->tensorboard) (1.16.0)
Requirement already satisfied: cachetools<6.0,>=2.0.0 in /usr/local/lib/pyth
on3.9/dist-packages (from google-auth<3,>=1.6.3->tensorboard) (5.3.0)
Requirement already satisfied: requests-oauthlib>=0.7.0 in /usr/local/lib/py
thon3.9/dist-packages (from google-auth-oauthlib<1.1,>=0.5->tensorboard) (1.
3.1)
Requirement already satisfied: importlib-metadata>=4.4 in /usr/local/lib/pyt
hon3.9/dist-packages (from markdown>=2.6.8->tensorboard) (6.2.0)
Requirement already satisfied: idna<4,>=2.5 in /usr/local/lib/python3.9/dist
-packages (from requests<3,>=2.21.0->tensorboard) (3.4)
Requirement already satisfied: urllib3<1.27,>=1.21.1 in /usr/local/lib/pytho
n3.9/dist-packages (from requests<3,>=2.21.0->tensorboard) (1.26.15)
Requirement already satisfied: certifi>=2017.4.17 in /usr/local/lib/python3.
9/dist-packages (from requests<3,>=2.21.0->tensorboard) (2022.12.7)
Requirement already satisfied: charset-normalizer~=2.0.0 in /usr/local/lib/p
ython3.9/dist-packages (from requests<3,>=2.21.0->tensorboard) (2.0.12)
Requirement already satisfied: MarkupSafe>=2.1.1 in /usr/local/lib/python3.
9/dist-packages (from werkzeug>=1.0.1->tensorboard) (2.1.2)
Requirement already satisfied: zipp>=0.5 in /usr/local/lib/python3.9/dist-pa
ckages (from importlib-metadata>=4.4->markdown>=2.6.8->tensorboard) (3.15.0)
Requirement already satisfied: pyasn1<0.5.0,>=0.4.6 in /usr/local/lib/python
```

```
3.9/dist-packages (from pyasn1-modules>=0.2.1->google-auth<3,>=1.6.3->tensor
board) (0.4.8)
Requirement already satisfied: oauthlib>=3.0.0 in /usr/local/lib/python3.9/d
ist-packages (from requests-oauthlib>=0.7.0->google-auth-oauthlib<1.1,>=0.5-
>tensorboard) (3.2.2)
```

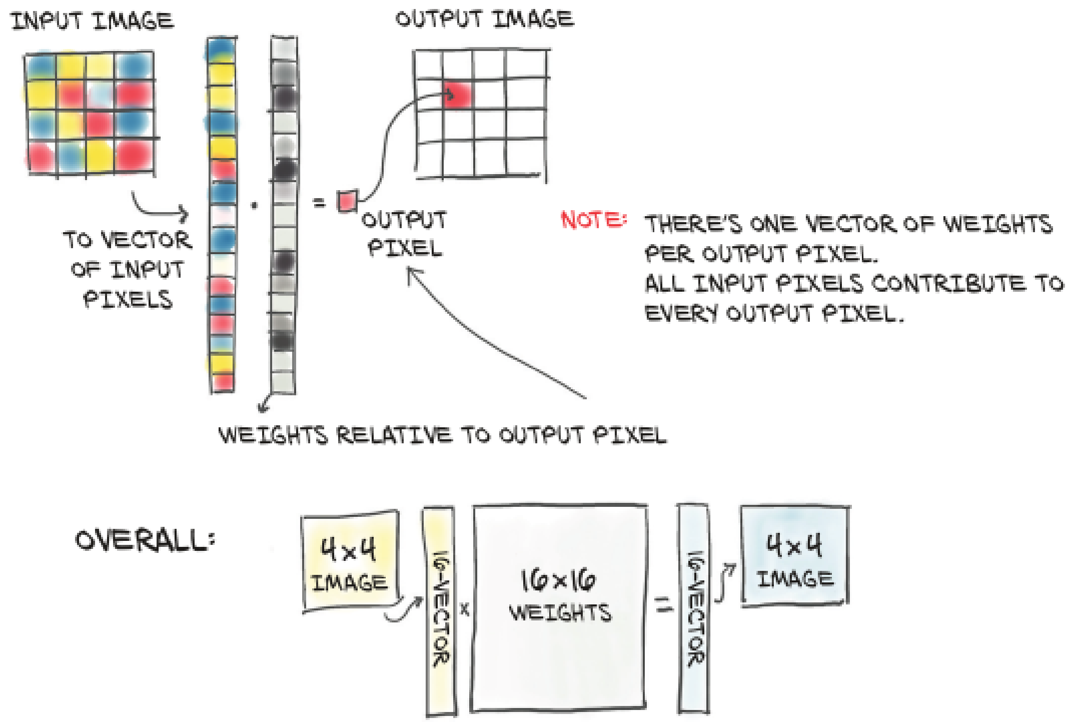
In [ ]:

```
%load_ext tensorboard
%tensorboard --logdir=runs
```

In [44]:

```
from torch.utils.tensorboard import SummaryWriter
import os
writer = SummaryWriter()

loss = torch.nn.CrossEntropyLoss()
# TODO:
# Define model = ?

model = tnn.Sequential(
    tnn.Flatten(),
    tnn.Linear(3*32*32, 100),
    tnn.ReLU(),
    tnn.Linear(100, 10))




def loss_and_accuracy(model, loss, validation_dataloader, device=DEVICE):
        # Validation loop
        validation_size = len(validation_dataloader.dataset)
        num_batches = len(validation_dataloader)
        test_loss, correct = 0, 0

        with torch.no_grad():
            model.eval() # Put model in eval mode, affects layers like dropo
            for X, y in validation_dataloader:
                X = X.to(device)
                y = y.to(device)
                pred = model(X)
                test_loss += loss(pred, y)
                correct += (pred.argmax(dim=-1) == y).type(DTYPE).sum()

        test_loss /= num_batches
        correct /= validation_size
        return test_loss, correct

def train(model, loss, training_dataloader, validation_dataloader, device=DE
    # Define optimizer
    optimizer = torch.optim.SGD(model.parameters(), lr=learning_rate, moment
    model.to(device)
    t0 = 0
    if not ignore_chkpt and os.path.exists(f"runs/{chkpt_name}"):
        checkpoint = torch.load(f"runs/{chkpt_name}")
        model.load_state_dict(checkpoint['model_state_dict'])
        optimizer.load_state_dict(checkpoint['optimizer_state_dict'])
        t0 = checkpoint['epoch']
    for t in range(t0, epochs):
        # Train loop
        training_size = len(training_dataloader.dataset)
        nbatches = len(training_dataloader)
        model.train() # Put model in train mode, affects layers like dropout
        for batch, (X, y) in enumerate(training_dataloader):
            X = X.to(device)
            y = y.to(device)
            # Compute prediction and loss
            pred = model(X)
            loss_t = loss(pred, y)

            # Backpropagation
            optimizer.zero_grad()
            loss_t.backward()
            optimizer.step()

            if batch % 100 == 0:
                writer.add_scalar("Train/loss_batch", loss_t,  t*nbatches +
                loss_t, current = loss_t.item(), (batch + 1) * len(X)
                print(f"loss: {loss_t:>7f}  [{current:>5d}/{training_size:>5

        writer.add_scalar("Train/loss", loss_t, t)
        valid_loss, correct = loss_and_accuracy(model, loss, validation_data
        writer.add_scalar("Valid/loss", valid_loss, t)
        writer.add_scalar("Valid/accuracy", correct, t)
        print(f"Validation Error: \n Accuracy: {(100*correct):>0.1f}%, Avg l
        if t % 3 == 0:
            torch.save({
                'epoch': t,
                'model_state_dict': model.state_dict(),
                'optimizer_state_dict': optimizer.state_dict()
                }, f"runs/{chkpt_name}")
    return model

# trained_model = train(model, loss, training_dataloader, validation_dataloa

# test_loss, correct = loss_and_accuracy(model, loss, test_dataloader)
# print(f"Test Error: \n Accuracy: {(100*correct):>0.1f}%, Avg loss: {test_l
```

Limits of fully connected layers


INPUT IMAGE
OUTPUT IMAGE
TO VECTOR OF INPUT PIXELS
OUTPUT PIXEL
NOTE: THERE'S ONE VECTOR OF WEIGHTS PER OUTPUT PIXEL.
ALL INPUT PIXELS CONTRIBUTE TO EVERY OUTPUT PIXEL.
WEIGHTS RELATIVE TO OUTPUT PIXEL
OVERALL:
4x4 IMAGE
16-VECTOR
x
16x16 WEIGHTS
=
16-VECTOR
4x4 IMAGE

Convolutions bring translation invariance

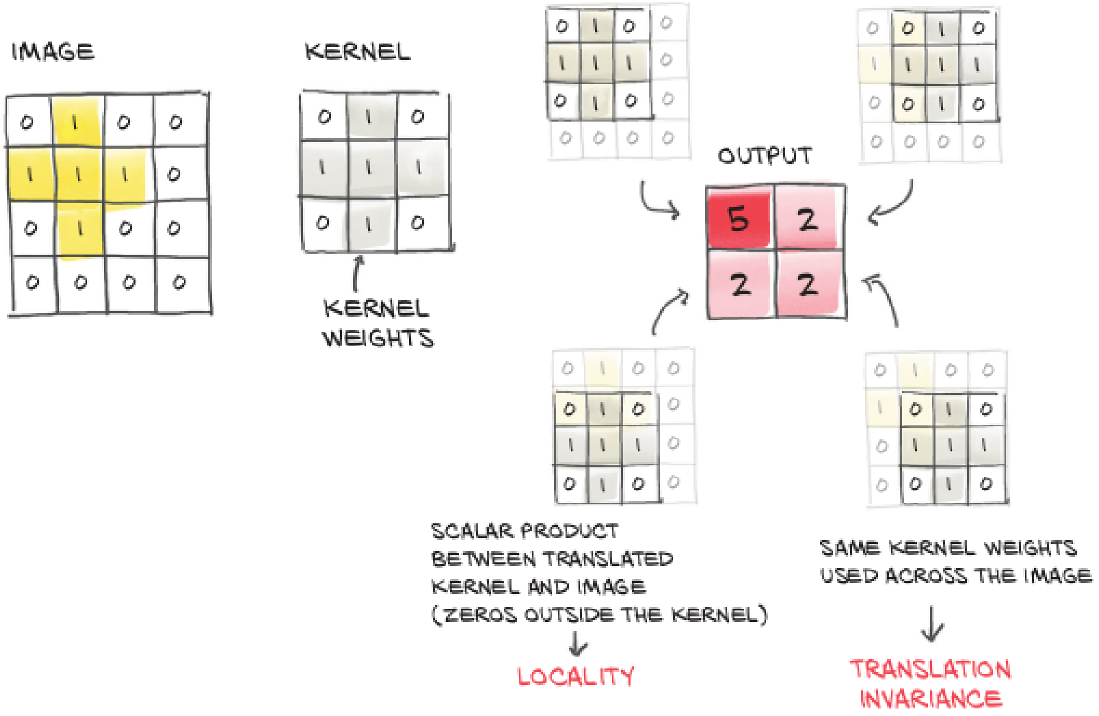
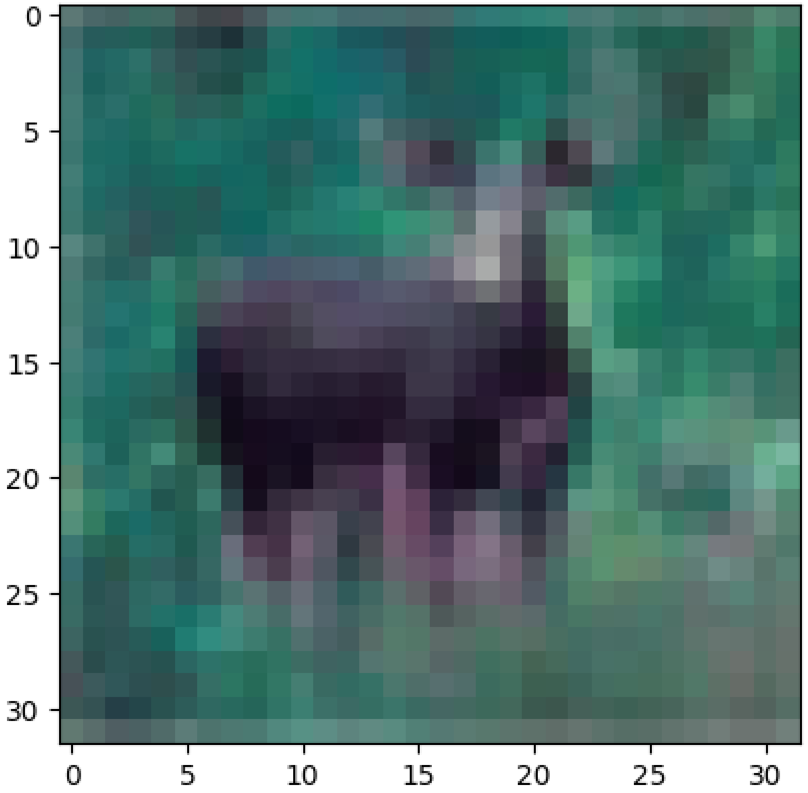


IMAGE
0 1 0 0
1 1 1 0
0 1 0 0
0 0 0 0
KERNEL
0 1 0
1 1 1
0 1 0
KERNEL WEIGHTS
OUTPUT
5 2
2 2
SCALAR PRODUCT BETWEEN TRANSLATED KERNEL AND IMAGE (ZEROS OUTSIDE THE KERNEL)
LOCALITY
SAME KERNEL WEIGHTS USED ACROSS THE IMAGE
TRANSLATION INVARIANCE

```
In [ ]: img, label = training_data[99]
        plt.imshow(img.permute(1, 2, 0) * t.Tensor(DATASET_STD) + t.Tensor(DATASET_M

Out[ ]: <matplotlib.image.AxesImage at 0x7feac18e0d00>
```



In [ ]:

```
!mkdir -p imgs
!wget "http://cliparts.co/cliparts/Aib/KoG/AibKoGRzT.png" -O imgs/sobel.png
```

```
--2023-04-11 18:15:05--  http://cliparts.co/cliparts/Aib/KoG/AibKoGRzT.png
Resolving cliparts.co (cliparts.co)... 173.208.212.194
Connecting to cliparts.co (cliparts.co)|173.208.212.194|:80... connected.
HTTP request sent, awaiting response... 200 OK
Length: 248899 (243K) [image/png]
Saving to: ‘imgs/sobel.png’

imgs/sobel.png      100%[===================>] 243.07K   501KB/s    in 0.5s

2023-04-11 18:15:06 (501 KB/s) - ‘imgs/sobel.png’ saved [248899/248899]
```

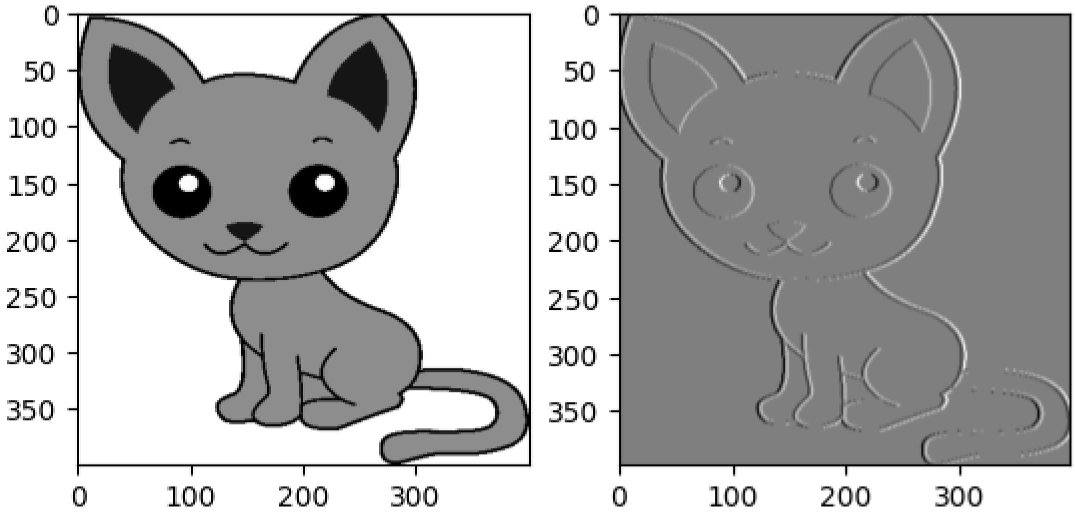
In [ ]:

```
conv = torch.nn.Conv2d(1, 1, kernel_size=3).to(DEVICE)

print(list(conv.named_parameters()))
with torch.no_grad():
    conv.weight[:] = torch.Tensor([[[-1, 0, 1],
                                    [-1, 0, 1],
                                    [-1, 0, 1]]])
    conv.bias[:] = 0
sobelimg = torchvision.io.read_image('imgs/sobel.png').to(DEVICE)
sobelimg = torchvision.transforms.functional.resize(sobelimg, (400, 400))
sobelimg = torchvision.transforms.functional.rgb_to_grayscale(sobelimg[:3, .
sobelimg = sobelimg.to(DTYPE) / sobelimg.max()

conved = conv(sobelimg)

fig, axes = plt.subplots(1, 2)
```

```
axes[0].imshow(sobelimg[0].detach().cpu(), cmap='gray')
axes[1].imshow(conved[0].detach().cpu(), cmap='gray')
```

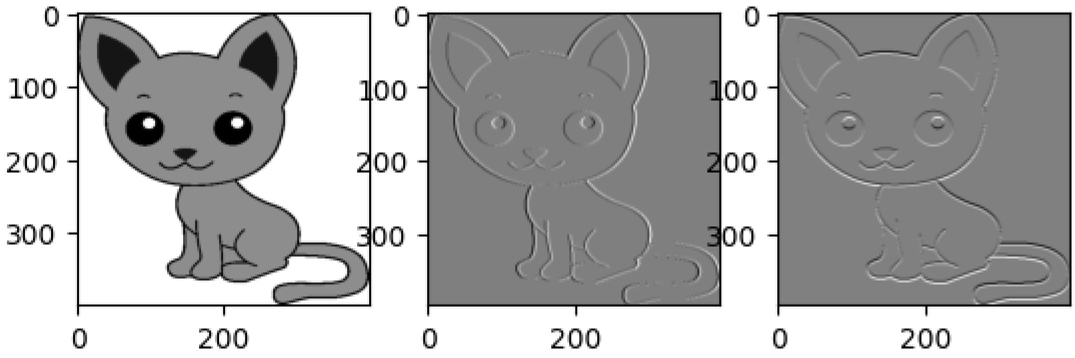
```
[('weight', Parameter containing:
tensor([[[[-0.2667, -0.0684,  0.0015],
          [ 0.0508,  0.2152,  0.2220],
          [ 0.2655,  0.0926, -0.1547]]]], device='cuda:0', requires_grad=Tru
e)), ('bias', Parameter containing:
tensor([0.1529], device='cuda:0', requires_grad=True))]
```

```
Out[ ]:  <matplotlib.image.AxesImage at 0x7fea1d2ccbe0>
```



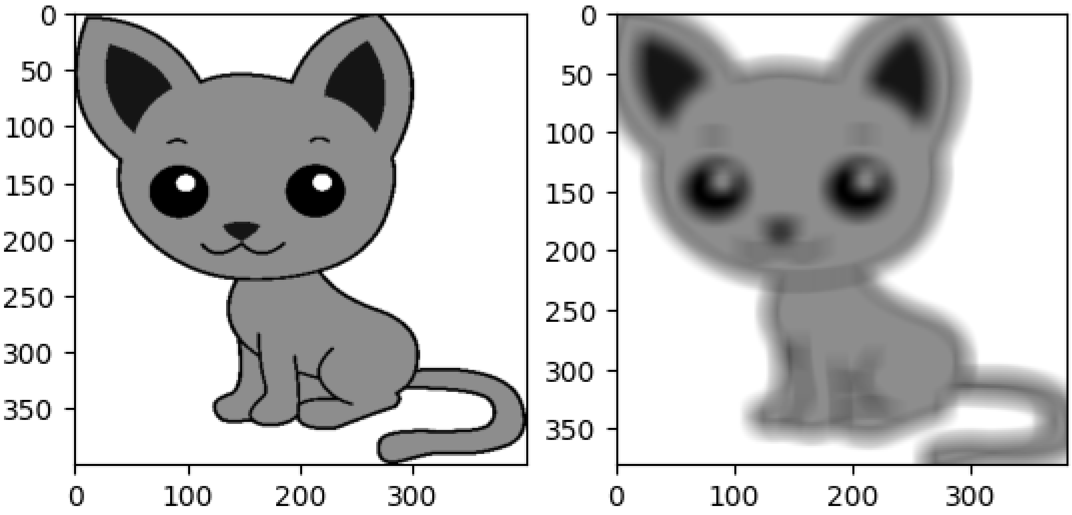
```
In [ ]:  with torch.no_grad():
             conv.weight[:] = torch.Tensor([[[[-1, -1, -1],
                                              [ 0,  0,  0],
                                              [ 1,  1,  1]]]])
             conv.bias[:] = 0

         conved2 = conv(sobelimg)

         fig, axes = plt.subplots(1, 3)
         axes[0].imshow(sobelimg[0].detach().cpu(), cmap='gray')
         axes[1].imshow(conved[0].detach().cpu(), cmap='gray')
         axes[2].imshow(conved2[0].detach().cpu(), cmap='gray')
```

```
Out[ ]:  <matplotlib.image.AxesImage at 0x7fea240aef40>
```



In [ ]:
```
import math
ks=20
conv = torch.nn.Conv2d(1, 1, kernel_size=ks).to(DEVICE)

with torch.no_grad():
    imin = -ks//2
    imax = imin + ks
    i = torch.arange(imin, imax).to(DTYPE)
    j = torch.arange(imin, imax).to(DTYPE)
    sigma = torch.Tensor([ks//6])

    grid_x, grid_y = torch.meshgrid(i, j, indexing='ij')
    #conv.weight[:] = torch.exp(-  (grid_x**2 + grid_y**2 ) / (2*sigma**2))
    conv.weight[:] = torch.ones((ks, ks)) / ks**2
    conv.bias[:] = 0

conved2 = conv(sobelimg)

fig, axes = plt.subplots(1, 2)
axes[0].imshow(sobelimg[0].detach().cpu(), cmap='gray')
axes[1].imshow(conved2[0].detach().cpu(), cmap='gray')
```

Out[ ]:
```
<matplotlib.image.AxesImage at 0x7fea1c5e1af0>
```



In [ ]:
```
!wget https://github.com/rajatsaxena/OpenCV/raw/master/mario.jpg -O imgs/mar
!wget https://github.com/rajatsaxena/OpenCV/raw/master/mario_template.jpg -O
```

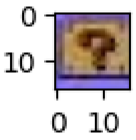
```
--2023-04-11 18:15:12--  https://github.com/rajatsaxena/OpenCV/raw/master/ma
rio.jpg
Resolving github.com (github.com)... 140.82.121.4
Connecting to github.com (github.com)|140.82.121.4|:443... connected.
HTTP request sent, awaiting response... 302 Found
Location: https://raw.githubusercontent.com/rajatsaxena/OpenCV/master/mario.
jpg [following]
--2023-04-11 18:15:12--  https://raw.githubusercontent.com/rajatsaxena/OpenC
V/master/mario.jpg
Resolving raw.githubusercontent.com (raw.githubusercontent.com)... 185.199.1
08.133, 185.199.109.133, 185.199.110.133, ...
Connecting to raw.githubusercontent.com (raw.githubusercontent.com)|185.199.
108.133|:443... connected.
HTTP request sent, awaiting response... 200 OK
Length: 7301 (7.1K) [image/jpeg]
Saving to: ‘imgs/mario.jpg’

imgs/mario.jpg      100%[===================>]   7.13K  --.-KB/s    in 0s

2023-04-11 18:15:12 (55.6 MB/s) - ‘imgs/mario.jpg’ saved [7301/7301]

--2023-04-11 18:15:12--  https://github.com/rajatsaxena/OpenCV/raw/master/ma
rio_template.jpg
Resolving github.com (github.com)... 140.82.121.3
Connecting to github.com (github.com)|140.82.121.3|:443... connected.
HTTP request sent, awaiting response... 302 Found
Location: https://raw.githubusercontent.com/rajatsaxena/OpenCV/master/mario_
template.jpg [following]
--2023-04-11 18:15:12--  https://raw.githubusercontent.com/rajatsaxena/OpenC
V/master/mario_template.jpg
Resolving raw.githubusercontent.com (raw.githubusercontent.com)... 185.199.1
08.133, 185.199.109.133, 185.199.110.133, ...
Connecting to raw.githubusercontent.com (raw.githubusercontent.com)|185.199.
108.133|:443... connected.
HTTP request sent, awaiting response... 200 OK
Length: 855 [image/jpeg]
Saving to: ‘imgs/mario_template.jpg’

imgs/mario_template 100%[===================>]     855  --.-KB/s    in 0s

2023-04-11 18:15:13 (41.1 MB/s) - ‘imgs/mario_template.jpg’ saved [855/855]
```

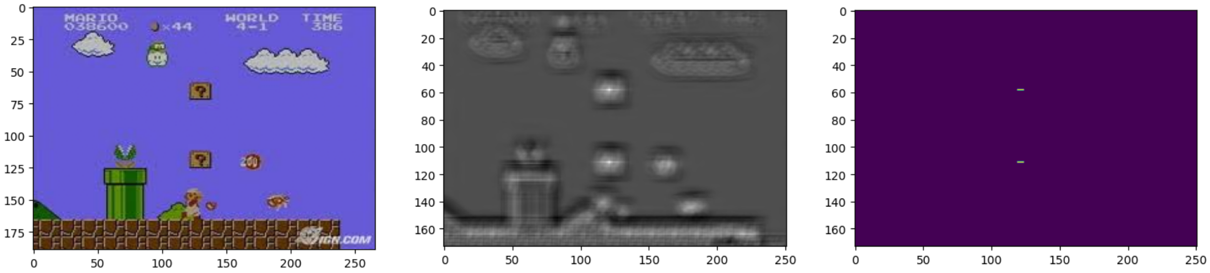
In [ ]:

```
with torch.no_grad():
    sobelimg = torchvision.io.read_image('imgs/mario.jpg').to(DEVICE)
    #sobelimg = torchvision.transforms.functional.rgb_to_grayscale(sobelimg[
    sobelimg = sobelimg.to(DTYPE) / sobelimg.max()

    patch = torchvision.io.read_image('imgs/mario_template.jpg').to(DEVICE)
    #patch = torchvision.transforms.functional.rgb_to_grayscale(patch[:3, ..
    patch = patch.to(DTYPE) / patch.max()
    fig, ax = plt.subplots(figsize=(0.5,0.5))
    ax.imshow(patch.permute(1, 2, 0).cpu())

kr, kc = patch.shape[1:]
conv = torch.nn.Conv2d(3, 1, kernel_size=(kr, kc)).to(DEVICE)
```

```python
with torch.no_grad():
    patch = (patch - patch.mean()) / patch.std()
    conv.weight[:] = patch
    conv.bias[:] = 0

sobelimgnormed = (sobelimg - sobelimg.mean()) / sobelimg.std()
conved2 = conv(sobelimgnormed)

fig, axes = plt.subplots(1, 3, figsize=(18, 6))
axes[0].imshow(sobelimg.permute(1, 2, 0).detach().cpu())
axes[1].imshow(conved2[0].detach().cpu(), cmap='gray')
axes[2].imshow((conved2[0].abs() > 380).detach().cpu())
```

```
Out[ ]: <matplotlib.image.AxesImage at 0x7fea1d62fa00>
```





Learning with Convolutions

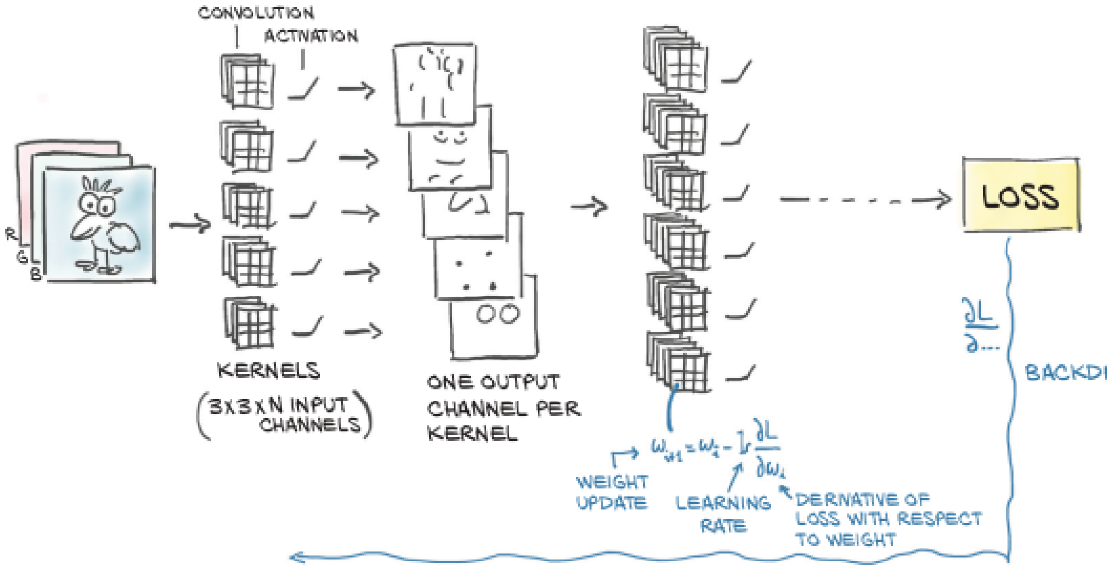

CONVOLUTION
ACTIVATION
R
G
B
KERNELS
(3X3XN INPUT CHANNELS)
ONE OUTPUT CHANNEL PER KERNEL
LOSS
$\frac{\partial L}{\partial ...}$
BACKDI
$\omega_{i+1} = \omega_i - lr \frac{\partial L}{\partial \omega_i}$
WEIGHT UPDATE
LEARNING RATE
DERIVATIVE OF LOSS WITH RESPECT TO WEIGHT

Figure 8.6 The process of learning with convolutions by estimating the gradient at the kernel weights and updating them individually in order to optimize for the loss

Maxpooling

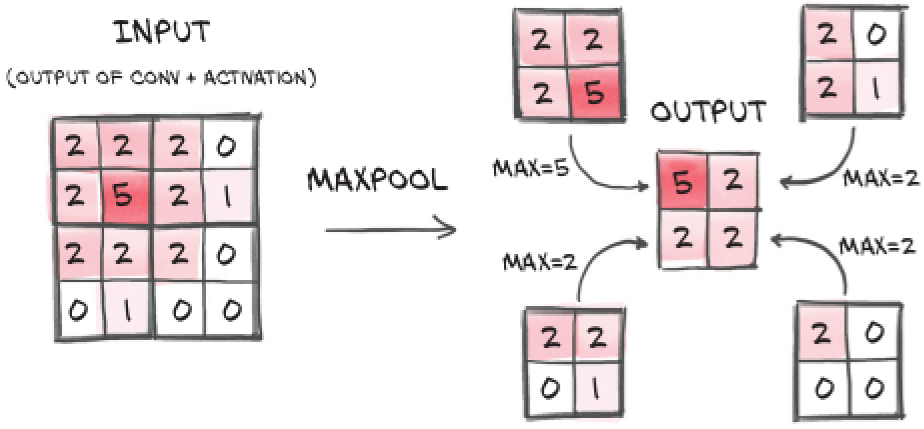


Figure 8.7 Max pooling in detail

In [ ]:
```
conv = tnn.Conv2d(3, 16, 3, stride=2, padding=1) # number of weights = 3*3 *
img, label = training_data[99]
conv(img).shape
```

Out[ ]:
```
torch.Size([16, 16, 16])
```

In [ ]:
```
import os

torch.manual_seed(17)
DATASET_MEAN = [0.4914, 0.4822, 0.4465]
DATASET_STD = [0.2470, 0.2435, 0.2616]
# Getting the dataset, the Pytorch way
all_training_data = torchvision.datasets.CIFAR10(
    root="data",
    train=True,
    download=True,
    transform=Compose([ToTensor(),
                       Normalize(DATASET_MEAN, # dataset mean
                                 DATASET_STD)]) # dataset std
)

test_data = torchvision.datasets.CIFAR10(
    root="data",
    train=False,
    download=True,
    transform=Compose([ToTensor(),
                       Normalize(DATASET_MEAN, # dataset mean
                                 DATASET_STD)]) # dataset std
)

training_data, validation_data = torch.utils.data.random_split(all_training_

training_dataloader = DataLoader(training_data, shuffle=True, batch_size=bat
validation_dataloader = DataLoader(validation_data,  batch_size=batch_size)
test_dataloader = DataLoader(test_data,  batch_size=batch_size)
```

```
loss = torch.nn.CrossEntropyLoss()
model = tnn.Sequential(
    tnn.Conv2d(3, 16, 3, padding=1), # 32x32 image 3 channels
    tnn.ReLU(),
    tnn.MaxPool2d(2), # -> 16x16 image with 16 channels
    tnn.Conv2d(16, 16, 3, padding=1), # 16x16 image with 16 channels
    tnn.ReLU(),
    tnn.MaxPool2d(2), # -> 8x8 image with 16 channels
    tnn.Flatten(),
    tnn.Linear(16*8*8, 100),
    tnn.ReLU(),
    tnn.Linear(100, 10))

trained_model = train(model, loss, training_dataloader, validation_dataloade
                     chkpt_name='conv_model_chkpt.pt', ignore_chkpt=True)

test_loss, correct = loss_and_accuracy(model, loss, test_dataloader)
print(f"Test Error: \n Accuracy: {(100*correct):>0.1f}%, Avg loss: {test_los
```

```
Files already downloaded and verified
Files already downloaded and verified
Validation Error:
 Accuracy: 35.3%, Avg loss: 1.825797

Validation Error:
 Accuracy: 43.3%, Avg loss: 1.586233
```

In [ ]:

```

```