EE 046746 - Technion - Computer Vision

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Appendix Tutorial - Visualizing CNN Filters

Agenda

In [1]:

```python
# imports for the tutorial
import numpy as np
import matplotlib.pyplot as plt
import seaborn as sns
from PIL import Image

# pytorch
import torch
import torch.nn as nn
import torchvision

# import datasets in torchvision
import torchvision.datasets as datasets
# import model zoo in torchvision
import torchvision.models as models
import torchvision.transforms as transforms
from torchvision import utils
```

Visualizing CNN Filters

* In this appendix tutorial we are going to deonstrate how to visualize the filters in a trained CNN.
* We are going to present two approaches, choose the one you are most comfortable with, they are equivalent.

Approach 1

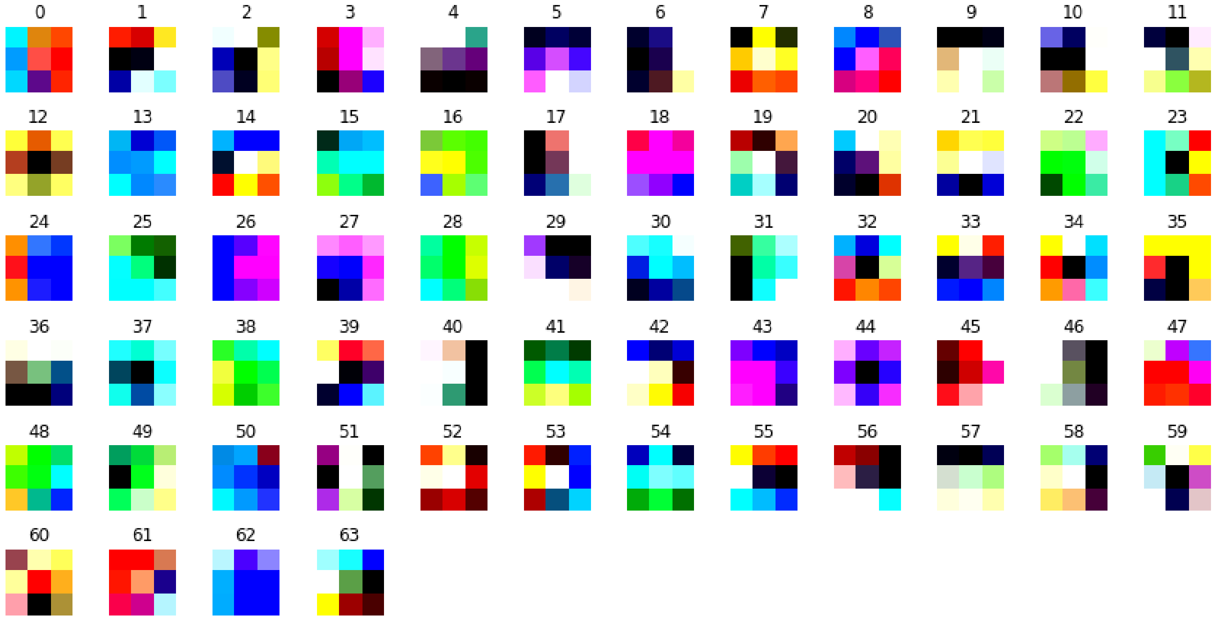
* Taken from this repo: https://github.com/Niranjankumar-c/DeepLearning-PadhAI/tree/master/DeepLearning_Materials/6_VisualizationCNN_Pytorch (https://github.com/Niranjankumar-c/DeepLearning-PadhAI/tree/master/DeepLearning_Materials/6_VisualizationCNN_Pytorch)

In [2]:
```python
# functions to visualize the kernels

def plot_filters_single_channel_big(t):

    #setting the rows and columns
    nrows = t.shape[0] * t.shape[2]
    ncols = t.shape[1] * t.shape[3]


    npimg = np.array(t.numpy(), np.float32)
    npimg = npimg.transpose((0, 2, 1, 3))
    npimg = npimg.ravel().reshape(nrows, ncols)

    npimg = npimg.T

    fig, ax = plt.subplots(figsize=(ncols/10, nrows/200))
#     fig, ax = plt.subplots(nrows=nrows, ncols=ncols)
    imgplot = sns.heatmap(npimg, xticklabels=False, yticklabels=False, cmap='gray', ax=ax, cbar=False)


def plot_filters_single_channel(t):

    # kernels depth * number of kernels
    nplots = t.shape[0] * t.shape[1]
    ncols = 12

    nrows = 1 + nplots // ncols
    # convert tensor to numpy image
    npimg = np.array(t.numpy(), np.float32)

    count = 0
    fig = plt.figure(figsize=(ncols, nrows))

    # looping through all the kernels in each channel
    for i in range(t.shape[0]):
        for j in range(t.shape[1]):
            count += 1
            ax1 = fig.add_subplot(nrows, ncols, count)
            npimg = np.array(t[i, j].numpy(), np.float32)
            npimg = (npimg - np.mean(npimg)) / np.std(npimg)
            npimg = np.minimum(1, np.maximum(0, (npimg + 0.5)))
            ax1.imshow(npimg)
            ax1.set_title(str(i) + ',' + str(j))
            ax1.axis('off')
            ax1.set_xticklabels([])
            ax1.set_yticklabels([])

    plt.tight_layout()


def plot_filters_multi_channel(t):

    # get the number of kernals
    num_kernels = t.shape[0]

    # define number of columns for subplots
    num_cols = 12
    # rows = num of kernels
    num_rows = num_kernels

    # set the figure size
    fig = plt.figure(figsize=(num_cols,num_rows))

    # looping through all the kernels
    for i in range(t.shape[0]):
        ax1 = fig.add_subplot(num_rows,num_cols,i+1)

        # for each kernel, we convert the tensor to numpy
        npimg = np.array(t[i].numpy(), np.float32)
        # standardize the numpy image
        npimg = (npimg - np.mean(npimg)) / np.std(npimg)
        npimg = np.minimum(1, np.maximum(0, (npimg + 0.5)))
        npimg = npimg.transpose((1, 2, 0))
        ax1.imshow(npimg)
        ax1.axis('off')
        ax1.set_title(str(i))
        ax1.set_xticklabels([])
        ax1.set_yticklabels([])

#     plt.savefig('myimage.png', dpi=100)
    plt.tight_layout()
```

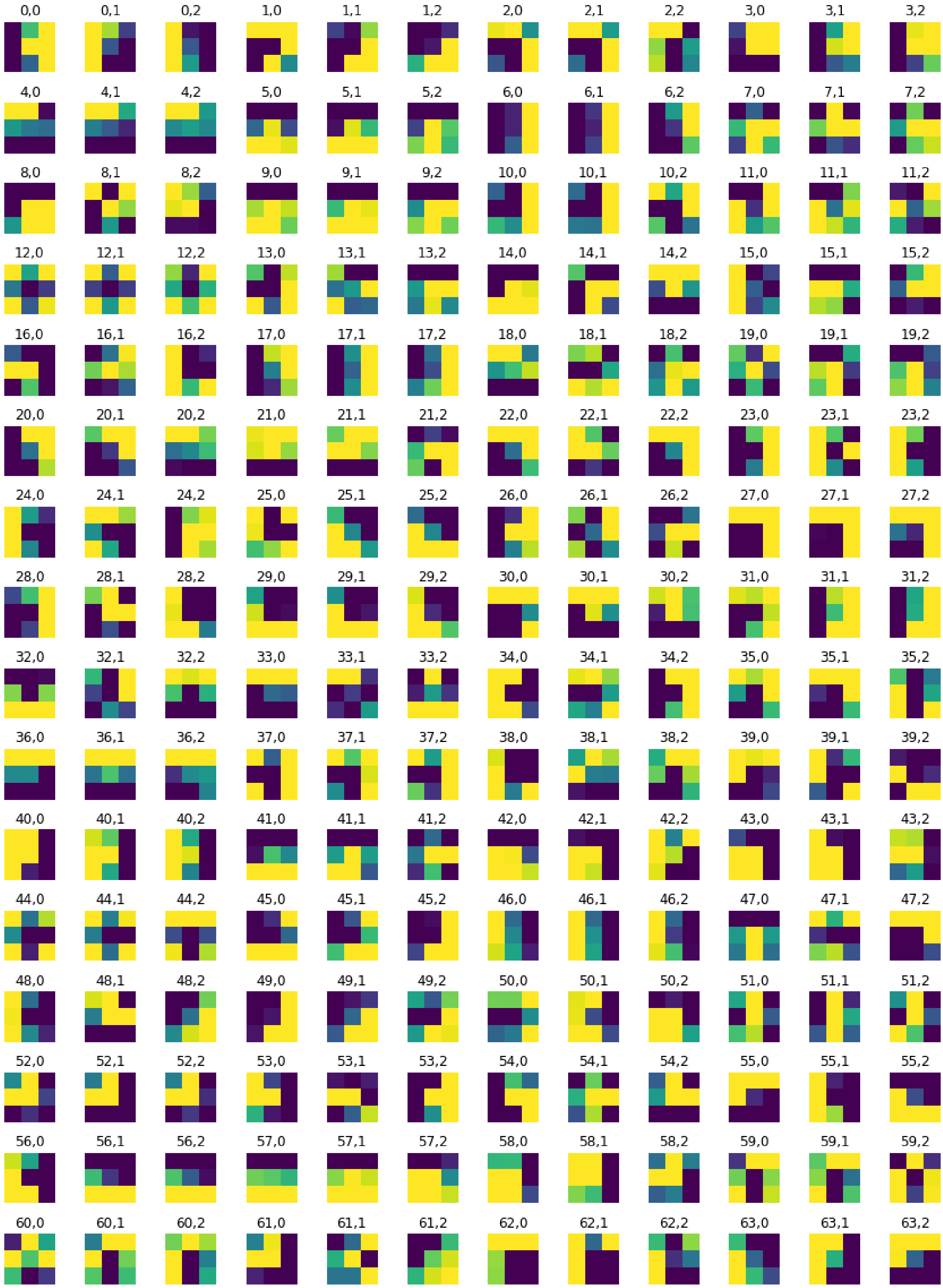
```python
def plot_weights(model, layer_num, single_channel=True, collated=False):
    # extracting the model features at the particular layer number
    layer = model.features[layer_num]

    # checking whether the layer is convolution layer or not
    if isinstance(layer, nn.Conv2d):
        # getting the weight tensor data
        weight_tensor = model.features[layer_num].weight.data

        if single_channel:
            if collated:
                plot_filters_single_channel_big(weight_tensor)
            else:
                plot_filters_single_channel(weight_tensor)
        else:
            if weight_tensor.shape[1] == 3:
                plot_filters_multi_channel(weight_tensor)
            else:
                print("Can only plot weights with three channels with single channel = False")
    else:
        print("Can only visualize layers which are convolutional")
```

In [3]:
```python
# for visualization we will use vgg16 pretrained on imagenet data
# load pretrained model
model = models.vgg16(pretrained=True)
# put in evaluation mode
model.eval();
```

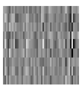
In [4]:
```python
# visualize weights for vgg16 - first conv layer
plot_weights(model, 0, single_channel=False)
```



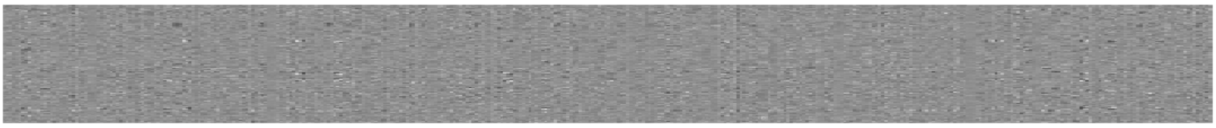
In [5]:
```python
# plotting single channel images
plot_weights(model, 0, single_channel=True)
```



In [6]:
```python
plot_weights(model, 0, single_channel=True, collated=True)
```



In [7]:
```python
plot_weights(model, 5, single_channel=True, collated=True)
```



2 Approach 2

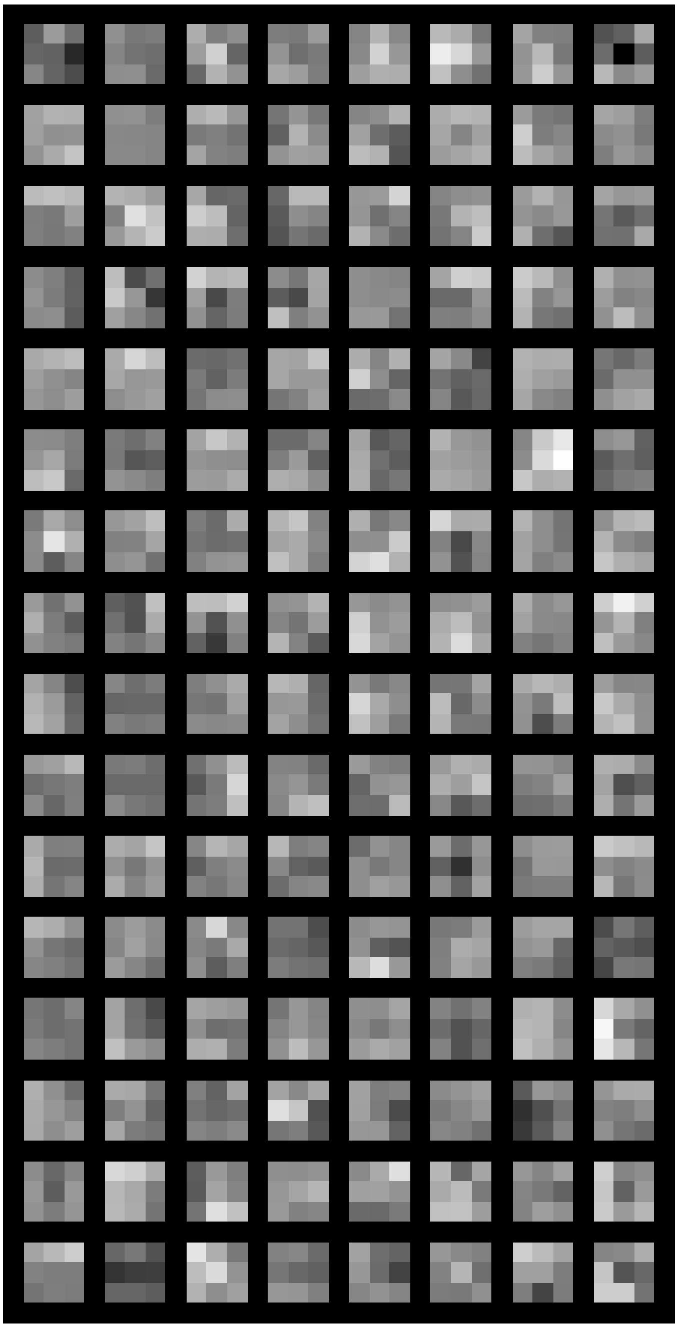
- Taken from this repo: https://github.com/pedrodiamel/nettutorial/blob/master/pytorch/pytorch_visualization.ipynb (https://github.com/pedrodiamel/nettutorial/blob/master/pytorch/pytorch_visualization.ipynb)

In [9]:
```python
# functions to visualize the kernels
def vistensor(tensor, ch=0, allkernels=False, nrow=8, padding=1):
    '''
    vistensor: visuzlization tensor
        @ch: visualization channel
        @allkernels: visualization all tensores
    '''

    n, c, w, h = tensor.shape
    if allkernels: tensor = tensor.view(n*c, -1, w, h )
    elif c != 3: tensor = tensor[:, ch, :, :].unsqueeze(dim=1)

    rows = np.min((tensor.shape[0] // nrow + 1, 64 ))
    grid = utils.make_grid(tensor, nrow=nrow, normalize=True, padding=padding)
    plt.figure(figsize=(nrow,rows))
    plt.imshow(grid.numpy().transpose((1, 2, 0)))

def savetensor(tensor, filename, ch=0, allkernels=False, nrow=8, padding=2):
    '''
    savetensor: save tensor
        @filename: file name
        @ch: visualization channel
        @allkernels: visualization all tensores
    '''

    n, c, w, h = tensor.shape
    if allkernels: tensor = tensor.view(n*c, -1, w, h )
    elif c != 3: tensor = tensor[:, ch, :, :].unsqueeze(dim=1)
    utils.save_image(tensor, filename, nrow=nrow )
```

In [12]:
```python
ik = 5
kernel = model.features[ik].weight.data.clone()
print(kernel.shape)

vistensor(kernel, ch=0, allkernels=False)
# savetensor(kernel, 'kernel.png', allkernels=False)

plt.axis('off')
```

```
torch.Size([128, 64, 3, 3])
```

Out[12]:
```
(-0.5, 32.5, 64.5, -0.5)
```

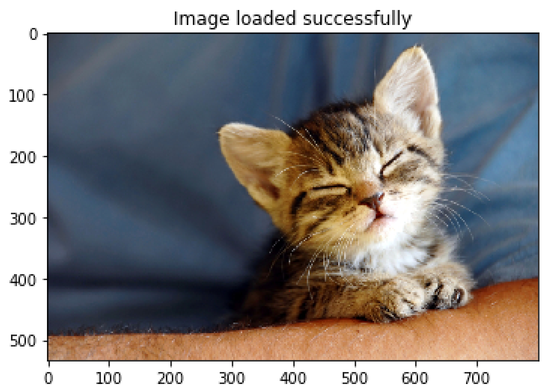


Visualizing Layer Output

- We can see which neurons are active for every input image.
- This way we can a better understanding of what the network sees during forward pass, whcih probably affects the final prediction.
- Taken from this repo: [https://github.com/sar-gupta/convisualize_nb/blob/master/cnn-visualize.ipynb (https://github.com/sar-gupta/convisualize_nb/blob/master/cnn-visualize.ipynb)](https://github.com/sar-gupta/convisualize_nb/blob/master/cnn-visualize.ipynb)

In [10]:
```python
# helper functions
def to_grayscale(image):
    """
    input is (d,w,h)
    converts 3D image tensor to grayscale images corresponding to each channel
    """
    image = torch.sum(image, dim=0)
    image = torch.div(image, image.shape[0])
    return image

def normalize(image, device=torch.device("cpu")):
    normalize = transforms.Normalize(
    mean=[0.485, 0.456, 0.406],
    std=[0.229, 0.224, 0.225]
    )
    preprocess = transforms.Compose([
    transforms.Resize((224,224)),
    transforms.ToTensor(),
    normalize
    ])
    image = preprocess(image).unsqueeze(0).to(device)
    return image


def predict(image, model, labels=None):
    _, index = model(image).data[0].max(0)
    if labels is not None:
        return str(index.item()), labels[str(index.item())][1]
    else:
        return str(index.item())

def deprocess(image, device=torch.device("cpu")):
    return image * torch.tensor([0.229, 0.224, 0.225]).to(device) + torch.tensor([0.485, 0.456, 0.406]).to
(device)

def load_image(path):
    image = Image.open(path)
    plt.imshow(image)
    plt.title("Image loaded successfully")
    return image
```

In [3]:
```python
# load sample image
kitten_img = load_image("./assets/sample_images/kitten.jpg")
```



In [4]:
```python
# load pre-trained model
device = torch.device("cuda:0" if torch.cuda.is_available() else "cpu")
model = models.vgg16(pretrained=True).to(device)
# put in evaluation mode
model.eval();
```

In [12]:
```python
# pre-process image and predict label
prep_img = normalize(kitten_img, device)
print("predicted class:", predict(prep_img, model))
```

```
predicted class: 281
```

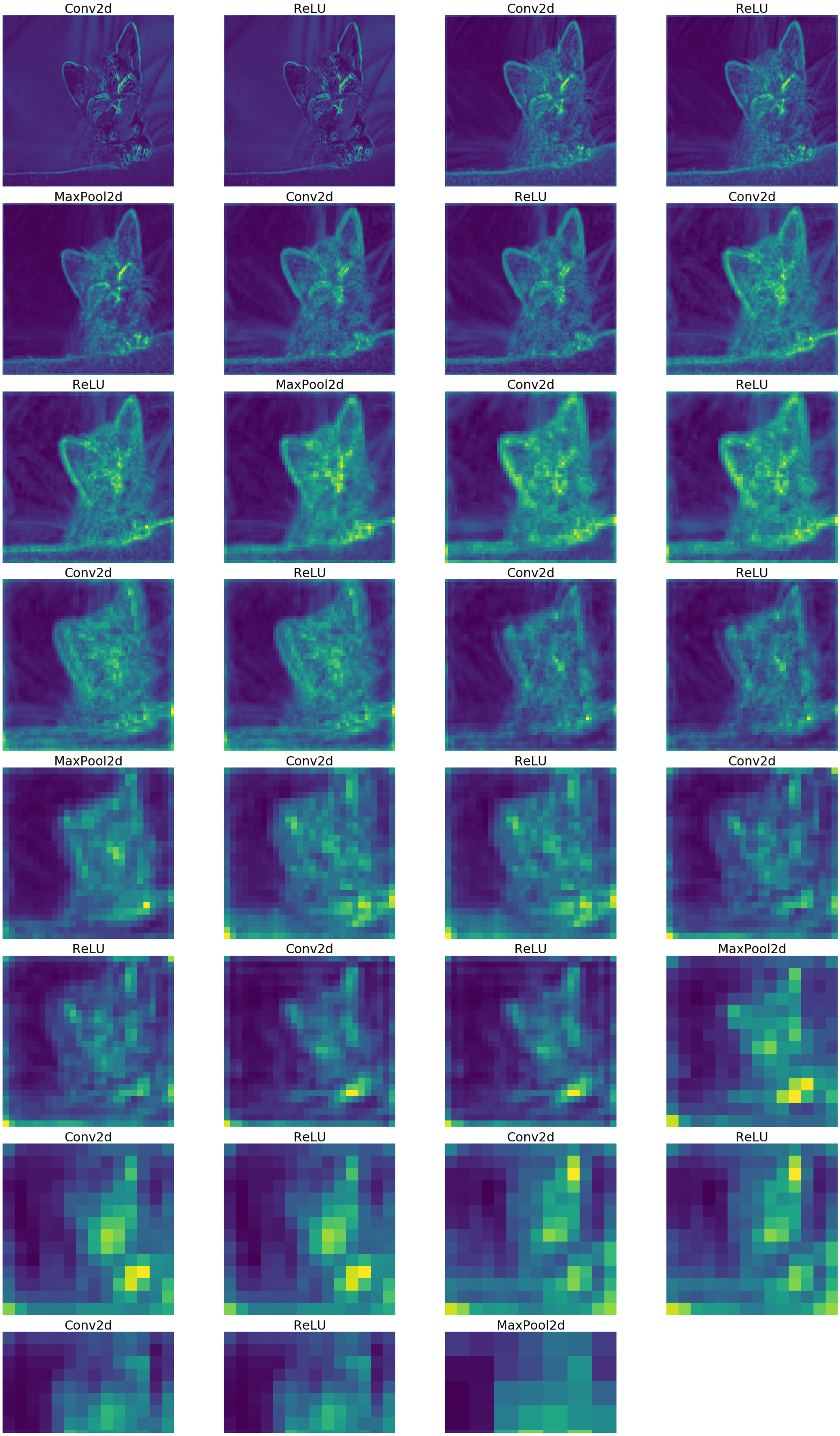
Output of Each Layer

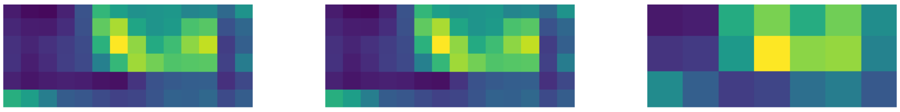
In [17]:

```python
def layer_outputs(image, model):
    modulelist = list(model.features.modules())
    outputs = []
    names = []
    for layer in modulelist[1:]:
        image = layer(image)
        outputs.append(image)
        names.append(str(layer))

    output_im = []
    for i in outputs:
        i = i.squeeze(0)
        temp = to_grayscale(i)
        output_im.append(temp.data.cpu().numpy())

    fig = plt.figure(figsize=(30, 50))

    for i in range(len(output_im)):
        a = fig.add_subplot(8, 4, i+1)
        imgplot = plt.imshow(output_im[i])
        a.set_axis_off()
        a.set_title(names[i].partition('(')[0], fontsize=30)
    plt.tight_layout()
#     plt.savefig('layer_outputs.jpg', bbox_inches='tight')
```

In [18]:

```
layer_outputs(prep_img, model)
```


Conv2d
ReLU
Conv2d
ReLU
MaxPool2d
Conv2d
ReLU
Conv2d
ReLU
MaxPool2d
Conv2d
ReLU
Conv2d
ReLU
Conv2d
ReLU
MaxPool2d
Conv2d
ReLU
Conv2d
ReLU
Conv2d
ReLU
MaxPool2d
Conv2d
ReLU
Conv2d
ReLU
Conv2d
ReLU
MaxPool2d



Output of Each Filter for a Certain Layer

In [22]:
```
def filter_outputs(image, model, layer_to_visualize):
    modulelist = list(model.features.modules())
    if layer_to_visualize < 0:
        layer_to_visualize += 31
    output = None
    name = None
    for count, layer in enumerate(modulelist[1:]):
        image = layer(image)
        if count == layer_to_visualize:
            output = image
            name = str(layer)

    filters = []
    output = output.data.squeeze().cpu().numpy()
    for i in range(output.shape[0]):
        filters.append(output[i,:,:])

    fig = plt.figure(figsize=(10, 10))

    for i in range(int(np.sqrt(len(filters))) * int(np.sqrt(len(filters)))):
        ax = fig.add_subplot(np.sqrt(len(filters)), np.sqrt(len(filters)), i+1)
        imgplot = ax.imshow(filters[i])
        ax.set_axis_off()
    plt.tight_layout()
```

In [23]:
```
filter_outputs(prep_img, model, 0)
```

Credits

- GitHub Repository 1 (https://github.com/Niranjankumar-c/DeepLearning-PadhAI/tree/master/DeepLearning_Materials/6_VisualizationCNN_Pytorch)
- GitHub Repository 2 (https://github.com/pedrodiamel/nettutorial/blob/master/pytorch/pytorch_visualization.ipynb)
- GitHub Repository 3 (https://github.com/sar-gupta/convisualize_nb/blob/master/cnn-visualize.ipynb)
- Icons from Icon8.com (https://icons8.com/) - https://icons8.com (https://icons8.com)