```
!git clone https://github.com/ClawSwipe/lrp_toolbox.git
```

```
Cloning into 'lrp_toolbox'...
remote: Enumerating objects: 2808, done.
remote: Counting objects: 100% (68/68), done.
remote: Compressing objects: 100% (56/56), done.
remote: Total 2808 (delta 31), reused 27 (delta 12), pack-reused 2740 (from 1)
Receiving objects: 100% (2808/2808), 414.35 MiB | 7.46 MiB/s, done.
Resolving deltas: 100% (1529/1529), done.
Updating files: 100% (64/64), done.
```

```
cd lrp_toolbox/python
```

```
/content/lrp_toolbox/python
```

Model IO

```
import os
import pickle
import numpy
import numpy as np
import importlib.util as imp
if imp.find_spec("cupy"):
    import cupy
    import cupy as np
na = np.newaxis

#--------------------
#   model reading
#--------------------

def read(path, fmt = None):
    '''
    Read neural network model from given path. Supported are files written in either plain text or via python's pickle module.

    Parameters
    ----------

    path : str
        the path to the file to read

    fmt : str
        optional. explicitly state how to interpret the target file. if not given, format is inferred from path.
        options are 'pickled','pickle','' and 'nn' to specify the pickle file format and 'txt' for a plain text
        format shared with the matlab implementation of the toolbox

    Returns
    -------
        model: modules.Sequential
            the  neural network model, realized as a sequence of network modules.

    Notes
    -----
        the plain text file format is shared with the matlab implementation of the LRP Toolbox and describes
        the model by listing its computational layers line by line as

        <Layername_i> [<input_size> <output_size>]
        [<Layer_params_i>]

        since all implemented modules except for modules.Linear operate point-wise on the given data, the optional
        information indicated by brackets [ ] is not used and only the name of the layer is witten, e.g.

        Rect

        Tanh

        SoftMax

        Flatten

        The exception formed by the linear layer implementation modules.Linear and modules.Convolution incorporates in raw text form as

        Linear m n
```

```
            W.flatten()
            B.flatten()

            with m and n being integer values describing the dimensions of the weight matrix W as [m x n] ,
            W being the human readable ascii-representation of the flattened matrix in m * n white space separated double values.
            After the line describing W, the bias term B is written out as a single line of n white space separated double values.

            Convolution h w d n s0 s1
            W.flatten()
            B.flatten()

            Semantics as above, with h, w, d being the filter heigth, width and depth and n being the number of filters of that layer.
            s0 and s1 specify the stride parameter in vertical (axis 0) and horizontal (axis 1) direction the layer operates on.

            Pooling layers have a parameterized one-line-description

            [Max|Sum]Pool h w s0 s1

            with h and w designating the pooling mask size and s0 and s1 the pooling stride.
        '''

        if not os.path.exists(path):
            raise IOError('model_io.read : No such file or directory: {0}'.format(path))

        if fmt is None: #try to infer format
            fmt = os.path.splitext(path)[1].replace('.','').lower()

        model = _read_as[fmt](path)
        if imp.find_spec("cupy"):
            model.to_cupy()
        return model


    def _read_pickled(path):
        print('loading pickled model from',path)
        with open(path,'rb') as f:
            p = pickle.load(f, encoding='latin1')
        return p


    def _read_txt(path):
        print('loading plain text model from',path)

        def _read_txt_helper(path):
            with open(path,'r') as f:
                content = f.read().split('\n')

                modules = []
                c = 0
                line = content[c]

                while len(line) > 0:
                    if line.startswith(Linear.__name__): # undefinedvar import error suppression for PyDev users
                        '''
                        Format of linear layer
                        Linear <rows_of_W> <columns_of_W>
                        <flattened weight matrix W>
                        <flattened bias vector>
                        '''
                        _,m,n = line.split();   m = int(m); n = int(n)
                        layer = Linear(m,n)
                        layer.W = np.array([float(weightstring) for weightstring in content[c+1].split() if len(weightstring) > 0]).reshape((m,r
                        layer.B = np.array([float(weightstring) for weightstring in content[c+2].split() if len(weightstring) > 0])
                        modules.append(layer)
                        c+=3 # the description of a linear layer spans three lines

                    elif line.startswith(Convolution.__name__): # undefinedvar import error suppression for PyDev users
                        '''
                        Format of convolution layer
                        Convolution <rows_of_W> <columns_of_W> <depth_of_W> <number_of_filters_W> <stride_axis_0> <stride_axis_1>
                        <flattened filter block W>
                        <flattened bias vector>
                        '''

                        _,h,w,d,n,s0,s1 = line.split()
                        h = int(h); w = int(w); d = int(d); n = int(n); s0 = int(s0); s1 = int(s1)
                        layer = Convolution(filtersize=(h,w,d,n), stride=(s0,s1))
```

```
                    layer.W = np.array([float(weightstring) for weightstring in content[c+1].split() if len(weightstring) > 0]).reshape((h,w
                    layer.B = np.array([float(weightstring) for weightstring in content[c+2].split() if len(weightstring) > 0])
                    modules.append(layer)
                    c+=3 #the description of a convolution layer spans three lines

                elif line.startswith(SumPool.__name__): # undefinedvar import error suppression for PyDev users
                    '''
                    Format of sum pooling layer
                    SumPool <mask_heigth> <mask_width> <stride_axis_0> <stride_axis_1>
                    '''

                    _,h,w,s0,s1 = line.split()
                    h = int(h); w = int(w); s0 = int(s0); s1 = int(s1)
                    layer = SumPool(pool=(h,w),stride=(s0,s1))
                    modules.append(layer)
                    c+=1 # one line of parameterized layer description

                elif line.startswith(MaxPool.__name__): # undefinedvar import error suppression for PyDev users
                    '''
                    Format of max pooling layer
                    MaxPool <mask_heigth> <mask_width> <stride_axis_0> <stride_axis_1>
                    '''

                    _,h,w,s0,s1 = line.split()
                    h = int(h); w = int(w); s0 = int(s0); s1 = int(s1)
                    layer = MaxPool(pool=(h,w),stride=(s0,s1))
                    modules.append(layer)
                    c+=1 # one line of parameterized layer description

                elif line.startswith(Flatten.__name__): # undefinedvar import error suppression for PyDev users
                    modules.append(Flatten()) ; c+=1 #one line of parameterless layer description
                elif line.startswith(Rect.__name__): # undefinedvar import error suppression for PyDev users
                    modules.append(Rect()) ; c+= 1 #one line of parameterless layer description
                elif line.startswith(Tanh.__name__): # undefinedvar import error suppression for PyDev users
                    modules.append(Tanh()) ; c+= 1 #one line of parameterless layer description
                elif line.startswith(SoftMax.__name__): # undefinedvar import error suppression for PyDev users
                    modules.append(SoftMax()) ; c+= 1 #one line of parameterless layer description
                else:
                    raise ValueError('Layer type identifier' + [s for s in line.split() if len(s) > 0][0] +  ' not supported for reading frc

                #skip info of previous layers, read in next layer header
                line = content[c]


        return Sequential(modules)
    # END _read_txt_helper()

    try:
        return _read_txt_helper(path)

    except ValueError as e:
        #numpy.reshape may throw ValueErros if reshaping does not work out.
        #In this case: fall back to reading the old plain text format.
        print('probable reshaping/formatting error while reading plain text network file.')
        print('ValueError message: {}'.format(e))
        print('Attempting fall-back to legacy plain text format interpretation...')
        return _read_txt_old(path)
        print('fall-back successfull!')


def _read_txt_old(path):
    print('loading plain text model from', path)

    with open(path, 'r') as f:
        content = f.read().split('\n')

        modules = []
        c = 0
        line = content[c]
        while len(line) > 0:
            if line.startswith(Linear.__name__): # undefinedvar import error suppression for PyDev users
                lineparts = line.split()
                m = int(lineparts[1])
                n = int(lineparts[2])
                mod = Linear(m,n)
                for i in range(m):
                    c+=1
```

```
                    mod.W[i,:] = np.array([float(val) for val in content[c].split() if len(val) > 0])

                c+=1
                mod.B = np.array([float(val) for val in content[c].split()])
                modules.append(mod)

            elif line.startswith(Rect.__name__): # undefinedvar import error suppression for PyDev users
                modules.append(Rect())
            elif line.startswith(Tanh.__name__): # undefinedvar import error suppression for PyDev users
                modules.append(Tanh())
            elif line.startswith(SoftMax.__name__): # undefinedvar import error suppression for PyDev users
                modules.append(SoftMax())
            else:
                raise ValueError('Layer type ' + [s for s in line.split() if len(s) > 0][0] +  ' not supported by legacy plain text format.'

            c+=1
            line = content[c]
        print(modules,'READ MODULES')
        return Sequential(modules)


_read_as = {'pickled': _read_pickled,\
            'pickle':_read_pickled,\
            'nn':_read_pickled,\
            '':_read_pickled,\
            'txt':_read_txt,\
            }




#--------------------
#   model writing
#--------------------

def write(model, path, fmt = None):
    '''
    Write neural a network model to a given path. Supported are either plain text or via python's pickle module.
    The model is cleaned of any temporary variables , e.g. hidden layer inputs or outputs, prior to writing

    Parameters
    ----------

    model : modules.Sequential
        the object representing the model.

    path : str
        the path to the file to read

    fmt : str
        optional. explicitly state how to write the file. if not given, format is inferred from path.
        options are 'pickled','pickle','' and 'nn' to specify the pickle file format and 'txt' for a plain text
        format shared with the matlab implementation of the toolbox

    Notes
    -----
        see the Notes - Section in the function documentation of model_io.read() for general info and a format
        specification of the plain text representation of neural network models
    '''

    model.clean()
    if not np == numpy: #np = cupy
        model.to_numpy() #TODO reconvert after writing?
    if fmt is None:
        fmt = os.path.splitext(path)[1].replace('.','').lower()

    _write_as[fmt](model, path)


def _write_pickled(model, path):
    print('writing model pickled to',path)
    with open(path, 'wb') as f:
        pickle.dump(model,f,pickle.HIGHEST_PROTOCOL)


def _write_txt(model,path):
    print('writing model as plain text to',path)
```

```
    if not isinstance(model, Sequential):
        raise Exception('Argument "model" must be an instance of module.Sequential, wrapping a sequence of neural network computation layers

    with open(path, 'w') as f:
        for layer in model.modules:
            if isinstance(layer,Linear):
                '''
                Format of linear layer
                Linear <rows_of_W> <columns_of_W>
                <flattened weight matrix W>
                <flattened bias vector>
                '''

                f.write('{0} {1} {2}\n'.format(layer.__class__.__name__,layer.m,layer.n))
                f.write(' '.join([repr(float(w)) for w in layer.W.flatten()]) + '\n')
                f.write(' '.join([repr(float(b)) for b in layer.B.flatten()]) + '\n')




            elif isinstance(layer,Convolution):
                '''
                    Format of convolution layer
                    Convolution <rows_of_W> <columns_of_W> <depth_of_W> <number_of_filters_W> <stride_axis_0> <stride_axis_1>
                    <flattened filter block W>
                    <flattened bias vector>
                '''

                f.write('{0} {1} {2} {3} {4} {5} {6}\n'.format(
                    layer.__class__.__name__,\
                    layer.fh,\
                    layer.fw,\
                    layer.fd,\
                    layer.n,\
                    layer.stride[0],\
                    layer.stride[1]
                ))
                f.write(' '.join([repr(float(w)) for w in layer.W.flatten()]) + '\n')
                f.write(' '.join([repr(float(b)) for b in layer.B.flatten()]) + '\n')

            elif isinstance(layer,SumPool):
                '''
                    Format of sum pooling layer
                    SumPool <mask_heigth> <mask_width> <stride_axis_0> <stride_axis_1>
                '''

                f.write('{0} {1} {2} {3} {4}\n'.format(
                    layer.__class__.__name__,\
                    layer.pool[0],\
                    layer.pool[1],\
                    layer.stride[0],\
                    layer.stride[1]))

            elif isinstance(layer,MaxPool):
                '''
                    Format of max pooling layer
                    MaxPool <mask_heigth> <mask_width> <stride_axis_0> <stride_axis_1>
                '''

                f.write('{0} {1} {2} {3} {4}\n'.format(
                    layer.__class__.__name__,\
                    layer.pool[0],\
                    layer.pool[1],\
                    layer.stride[0],\
                    layer.stride[1]))

            else:
                '''
                all other layers are free from parameters. Format is thus:
                <Layername>
                '''
                f.write(layer.__class__.__name__ + '\n')


_write_as = {'pickled': _write_pickled,\
             'pickle':_write_pickled,\
```

```
            'nn':_write_pickled,\
            '':_write_pickled,\
            'txt':_write_txt,\
            }
```

Data IO

```
import os
import scipy.io as scio

import numpy
import numpy as np
import importlib.util as imp
if imp.find_spec("cupy"):
    import cupy
    import cupy as np
na = np.newaxis



#--------------------
#   data reading
#--------------------

def read(path, fmt = None):
    '''
    Read [N x D]-sized block-formatted data from a given path.
    Supported data formats are
        plain text (ascii-matrices)
        numpy-compressed data (npy- or npz-files)
        matlab data files (mat-files)

    Parameters
    ----------

    path : str
        the path to the file to read

    fmt : str
        optional. if explicitly given, the file will be interpreted as mat, txt, npy or npz. elsewise, interpretation format will be inferre


    Returns
    -------

    data : numpy.ndarray

    '''
    if not os.path.exists(path):
        raise IOError('data_io.read : No such file or directory: {0}'.format(path))

    if fmt is None: #try to infer format
        fmt = os.path.splitext(path)[1].replace('.','').lower()

    data = _read_as[fmt](path)

    return data


def _read_np(path):
    print('loading np-formatted data from',path)
    return np.load(path)


def _read_mat(path):
    print('loading matlab formatted data from', path)
    return np.array(scio.loadmat(path)['data'])
```

```
    def _read_txt(path):
        print('loading plain text data from',path)
        return np.array(numpy.loadtxt(path))

    _read_as = {'npy':_read_np,\
                'npz':_read_np,\
                ''   :_read_np,\
                'mat':_read_mat,\
                'txt':_read_txt,\
                }


    #--------------------
    #   data writing
    #--------------------


    def write(data, path, fmt = None):
        '''
        Write [N x D]-sized block-formatted data to a given path.
        Supported data formats are
            plain text (ascii-matrices)
            numpy-compressed data (npy- or npz-files)
            matlab data files (mat-files)

        Parameters
        ----------

        data : numpy.ndarray
            a [N x D] - shaped, two-dimensional array of data.

        path : str
            the path to write the data to

        fmt : str
            optional. if explicitly given, the file will be written as mat, txt, npy or npz. elsewise, interpretation format will be inferred fr

        '''

        if fmt is None: #try to infer format
            fmt = os.path.splitext(path)[1].replace('.','').lower()

        _write_as[fmt](data,path)


    def _write_np(data, path):
        print('writing data in npy-format to',path)
        np.save(path, data)

    def _write_mat(data, path):
        print('writing data in mat-format to',path)
        if not numpy == np: #np == cupy
            data = np.asnumpy(data)
        scio.savemat(path, {'data':data}, appendmat = False)

    def _write_txt(data, path):
        print('writing data as plain text to',path)
        if not numpy == np: #np == cupy
            data = np.asnumpy(data)
        np.savetxt(path, data)


    _write_as = {'npy':_write_np,\
                 'npz':_write_np,\
                 ''   :_write_np,\
                 'mat':_write_mat,\
                 'txt':_write_txt,\
                }
```

Render

```
import numpy as np
import matplotlib.cm
from matplotlib.cm import ScalarMappable
import skimage.io
try:
    from skimage.feature import canny
except:
    from skimage.filter import canny


def vec2im(V, shape = () ):
    '''
    Transform an array V into a specified shape - or if no shape is given assume a square output format.

    Parameters
    ----------

    V : numpy.ndarray
        an array either representing a matrix or vector to be reshaped into an two-dimensional image

    shape : tuple or list
        optional. containing the shape information for the output array if not given, the output is assumed to be square

    Returns
    -------

    W : numpy.ndarray
        with W.shape = shape or W.shape = [np.sqrt(V.size)]*2

    '''

    if len(shape) < 2:
        shape = [int(np.sqrt(V.size))]*2

    return np.reshape(V, shape)


def enlarge_image(img, scaling = 3):
    '''
    Enlarges a given input matrix by replicating each pixel value scaling times in horizontal and vertical direction.

    Parameters
    ----------

    img : numpy.ndarray
        array of shape [H x W] OR [H x W x D]

    scaling : int
        positive integer value > 0

    Returns
    -------

    out : numpy.ndarray
        two-dimensional array of shape [scaling*H x scaling*W]
        OR
        three-dimensional array of shape [scaling*H x scaling*W x D]
        depending on the dimensionality of the input
    '''

    if scaling < 1 or not isinstance(scaling,int):
        print('scaling factor needs to be an int >= 1')

    if len(img.shape) == 2:
        H,W = img.shape

        out = np.zeros((scaling*H, scaling*W))
        for h in range(H):
            fh = scaling*h
            for w in range(W):
                fw = scaling*w
                out[fh:fh+scaling, fw:fw+scaling] = img[h,w]

    elif len(img.shape) == 3:
        H,W,D = img.shape

        out = np.zeros((scaling*H, scaling*W,D))
```

```
            for h in range(H):
                fh = scaling*h
                for w in range(W):
                    fw = scaling*w
                    out[fh:fh+scaling, fw:fw+scaling,:] = img[h,w,:]

        return out


    def repaint_corner_pixels(rgbimg, scaling = 3):
        '''
        DEPRECATED/OBSOLETE.

        Recolors the top left and bottom right pixel (groups) with the average rgb value of its three neighboring pixel (groups).
        The recoloring visually masks the opposing pixel values which are a product of stabilizing the scaling.
        Assumes those image ares will pretty much never show evidence.

        Parameters
        ----------

        rgbimg : numpy.ndarray
            array of shape [H x W x 3]

        scaling : int
            positive integer value > 0

        Returns
        -------

        rgbimg : numpy.ndarray
            three-dimensional array of shape [scaling*H x scaling*W x 3]
        '''



        #top left corner.
        rgbimg[0:scaling,0:scaling,:] = (rgbimg[0,scaling,:] + rgbimg[scaling,0,:] + rgbimg[scaling, scaling,:])/3.0
        #bottom right corner
        rgbimg[-scaling:,-scaling:,:] = (rgbimg[-1,-1-scaling, :] + rgbimg[-1-scaling, -1, :] + rgbimg[-1-scaling,-1-scaling,:])/3.0
        return rgbimg


    def digit_to_rgb(X, scaling=3, shape = (), cmap = 'binary'):
        '''
        Takes as input an intensity array and produces a rgb image due to some color map

        Parameters
        ----------

        X : numpy.ndarray
            intensity matrix as array of shape [M x N]

        scaling : int
            optional. positive integer value > 0

        shape: tuple or list of its , length = 2
            optional. if not given, X is reshaped to be square.

        cmap : str
            name of color map of choice. default is 'binary'

        Returns
        -------

        image : numpy.ndarray
            three-dimensional array of shape [scaling*H x scaling*W x 3] , where H*W == M*N
        '''

        #create color map object from name string
        cmap = eval('matplotlib.cm.{}'.format(cmap))

        image = enlarge_image(vec2im(X,shape), scaling) #enlarge
        image = cmap(image.flatten())[...,0:3].reshape([image.shape[0],image.shape[1],3]) #colorize, reshape

        return image
```

```
def hm_to_rgb(R, X = None, scaling = 3, shape = (), sigma = 2, cmap = 'gray-red2', normalize = True):
    '''
    Takes as input an intensity array and produces a rgb image for the represented heatmap.
    optionally draws the outline of another input on top of it.

    Parameters
    ----------

    R : numpy.ndarray
        the heatmap to be visualized, shaped [M x N]

    X : numpy.ndarray
        optional. some input, usually the data point for which the heatmap R is for, which shall serve
        as a template for a black outline to be drawn on top of the image
        shaped [M x N]

    scaling: int
        factor, on how to enlarge the heatmap (to control resolution and as a inverse way to control outline thickness)
        after reshaping it using shape.

    shape: tuple or list, length = 2
        optional. if not given, X is reshaped to be square.

    sigma : double
        optional. sigma-parameter for the canny algorithm used for edge detection. the found edges are drawn as outlines.

    cmap : str
        optional. color map of choice

    normalize : bool
        optional. whether to normalize the heatmap to [-1 1] prior to colorization or not.

    Returns
    -------

    rgbimg : numpy.ndarray
        three-dimensional array of shape [scaling*H x scaling*W x 3] , where H*W == M*N
    '''

    R = enlarge_image(vec2im(R,shape), scaling)

    if cmap in custom_maps:
        rgb =  custom_maps[cmap](R)
    else:
        if normalize:
            R = R / np.max(np.abs(R)) # normalize to [-1,1] wrt to max relevance magnitude
            R = (R + 1.)/2. # shift/normalize to [0,1] for color mapping

        #create color map object from name string
        cmap = eval('matplotlib.cm.{}'.format(cmap))

        # apply colormap
        rgb = cmap(R.flatten())[...,0:3].reshape([R.shape[0],R.shape[1],3])
    #rgb = repaint_corner_pixels(rgb, scaling) #obsolete due to directly calling the color map with [0,1]-normalized inputs

    if not X is None: #compute the outline of the input
        X = enlarge_image(vec2im(X,shape), scaling)
        xdims = X.shape
        Rdims = R.shape

        if not np.all(xdims == Rdims):
            print('transformed heatmap and data dimension mismatch. data dimensions differ?')
            print('R.shape = ',Rdims, 'X.shape = ', xdims)
            print('skipping drawing of outline\n')
        else:
            edges = canny(X, sigma=sigma)
            edges = np.invert(np.dstack([edges]*3))*1.0
            rgb *= edges # set outline pixels to black color

    return rgb


def save_image(rgb_images, path, gap = 2):
    '''
    Takes as input a list of rgb images, places them next to each other with a gap and writes out the result.

    Parameters
```

```
        ----------

        rgb_images : list , tuple, collection. such stuff
            each item in the collection is expected to be an rgb image of dimensions [H x _ x 3]
            where the width is variable

        path : str
            the output path of the assembled image

        gap : int
            optional. sets the width of a black area of pixels realized as an image shaped [H x gap x 3] in between the input images

        Returns
        -------

        image : numpy.ndarray
            the assembled image as written out to path
        '''

        sz = []
        image = []
        for i in range(len(rgb_images)):
            if not sz:
                sz = rgb_images[i].shape
                image = rgb_images[i]
                gap = np.zeros((sz[0],gap,sz[2]))
                continue
            if not sz[0] == rgb_images[i].shape[0] and sz[1] == rgb_images[i].shape[2]:
                print('image',i, 'differs in size. unable to perform horizontal alignment')
                print('expected: Hx_xD = {0}x_x{1}'.format(sz[0],sz[1]))
                print('got     : Hx_xD = {0}x_x{1}'.format(rgb_images[i].shape[0],rgb_images[i].shape[1]))
                print('skipping image\n')
            else:
                image = np.hstack((image,gap,rgb_images[i]))

        image *= 255
        image = image.astype(np.uint8)

        print('saving image to ', path)
        skimage.io.imsave(path,image)
        return image


    # ################## #
    # custom color maps: #
    # ################## #

    def gregoire_gray_red(R):
        basegray = 0.8 #floating point gray

        maxabs = np.max(R)
        RGB = np.ones([R.shape[0], R.shape[1],3]) * basegray #uniform gray image.

        tvals = np.maximum(np.minimum(R/maxabs,1.0),-1.0)
        negatives = R < 0

        RGB[negatives,0] += tvals[negatives]*basegray
        RGB[negatives,1] += tvals[negatives]*basegray
        RGB[negatives,2] += -tvals[negatives]*(1-basegray)

        positives = R>=0
        RGB[positives,0] += tvals[positives]*(1-basegray)
        RGB[positives,1] += -tvals[positives]*basegray
        RGB[positives,2] += -tvals[positives]*basegray

        return RGB


    def gregoire_black_green(R):
        maxabs = np.max(R)
        RGB = np.zeros([R.shape[0], R.shape[1],3])

        negatives = R<0
        RGB[negatives,2] = -R[negatives]/maxabs

        positives = R>=0
        RGB[positives,1] = R[positives]/maxabs
```

```
    return RGB


def gregoire_black_firered(R):
    R = R / np.max(np.abs(R))
    x = R

    hrp  = np.clip(x-0.00,0,0.25)/0.25
    hgp = np.clip(x-0.25,0,0.25)/0.25
    hbp = np.clip(x-0.50,0,0.50)/0.50

    hbn = np.clip(-x-0.00,0,0.25)/0.25
    hgn = np.clip(-x-0.25,0,0.25)/0.25
    hrn = np.clip(-x-0.50,0,0.50)/0.50

    return np.concatenate([(hrp+hrn)[...,None],(hgp+hgn)[...,None],(hbp+hbn)[...,None]],axis = 2)


def gregoire_gray_red2(R):
    v = np.var(R)
    R[R > 10*v] = 0
    R[R<0] = 0
    R = R / np.max(R)
    #(this is copypasta)
    x=R

    # positive relevance
    hrp = 0.9 - np.clip(x-0.3,0,0.7)/0.7*0.5
    hgp = 0.9 - np.clip(x-0.0,0,0.3)/0.3*0.5 - np.clip(x-0.3,0,0.7)/0.7*0.4
    hbp = 0.9 - np.clip(x-0.0,0,0.3)/0.3*0.5 - np.clip(x-0.3,0,0.7)/0.7*0.4

    # negative relevance
    hrn = 0.9 - np.clip(-x-0.0,0,0.3)/0.3*0.5 - np.clip(-x-0.3,0,0.7)/0.7*0.4
    hgn = 0.9 - np.clip(-x-0.0,0,0.3)/0.3*0.5 - np.clip(-x-0.3,0,0.7)/0.7*0.4
    hbn = 0.9 - np.clip(-x-0.3,0,0.7)/0.7*0.5

    hr = hrp*(x>=0)+hrn*(x<0)
    hg = hgp*(x>=0)+hgn*(x<0)
    hb = hbp*(x>=0)+hbn*(x<0)


    return np.concatenate([hr[...,None],hg[...,None],hb[...,None]],axis=2)



def alex_black_yellow(R):

    maxabs = np.max(R)
    RGB = np.zeros([R.shape[0], R.shape[1],3])

    negatives = R<0
    RGB[negatives,2] = -R[negatives]/maxabs

    positives = R>=0
    RGB[positives,0] = R[positives]/maxabs
    RGB[positives,1] = R[positives]/maxabs

    return RGB


#list of supported color map names. the maps need to be implemented ABOVE this line because of PYTHON
custom_maps = {'gray-red':gregoire_gray_red,\
'gray-red2':gregoire_gray_red2,\
'black-green':gregoire_black_green,\
'black-firered':gregoire_black_firered,\
'blue-black-yellow':alex_black_yellow}
```

Training Test MNIST

```
import importlib.util as imp
import numpy
import numpy as np
```

```
if imp.find_spec("cupy"): #use cupy for GPU support if available
    import cupy
    import cupy as np
na = np.newaxis

import modules
import model_io
import data_io


train_xor = True
train_mnist = True

if train_xor:
    D,N = 2,200000

    #this is the XOR problem.
    X = np.random.rand(N,D) #we want [NxD] data
    X = (X > 0.5)*1.0
    Y = X[:,0] == X[:,1]
    Y = (np.vstack((Y, np.invert(Y)))*1.0).T # and [NxC] labels. [1,0] for equal (output 0). [0,1] for different (output 1)

    X += np.random.randn(N,D)*0.1 # add some noise to the data.

    #build a network
    nn = modules.Sequential([modules.Linear(2,3),
                             modules.Tanh(),
                             modules.Linear(3,15),
                             modules.Tanh(),
                             modules.Linear(15,15),
                             modules.Tanh(),
                             modules.Linear(15,3),
                             modules.Tanh() ,
                             modules.Linear(3,2),
                             modules.SoftMax()])
    #train the network.
    nn.train(X,Y, batchsize = 5, iters=1000)
    xoracc = np.mean(np.argmax(nn.forward(X), axis=1) == np.argmax(Y, axis=1))
    if not np == numpy: # np=cupy
        xoracc = np.asnumpy(xoracc)
    print(' XOR problem: model train accuracy is: {:0.4f}'.format(xoracc))

    #save the network
    model_io.write(nn, '../xor_net_small_1000.txt')

if train_mnist:

    Xtrain = data_io.read('../data/MNIST/train_images.npy')
    Ytrain = data_io.read('../data/MNIST/train_labels.npy')
    Xtest = data_io.read('../data/MNIST/test_images.npy')
    Ytest = data_io.read('../data/MNIST/test_labels.npy')

    # transfer pixel values from [0 255] to [-1 1] to satisfy the expected input / training paradigm of the model
    Xtrain =  Xtrain / 127.5 - 1
    Xtest =  Xtest / 127.5 - 1

    # transform numeric class labels to vector indicator for uniformity. assume presence of all classes within the label set
    I = Ytrain[:,0].astype(int)
    Ytrain = np.zeros([Xtrain.shape[0],np.unique(Ytrain).size])
    Ytrain[np.arange(Ytrain.shape[0]),I] = 1

    I = Ytest[:,0].astype(int)
    Ytest = np.zeros([Xtest.shape[0],np.unique(Ytest).size])
    Ytest[np.arange(Ytest.shape[0]),I] = 1 #One hot encoding: Each label (which is a digit between 0 and 9) is transformed into a vector of si


    nn = modules.Sequential( #L1 Loss
        [
            modules.Flatten(), #28x28 image to 1D matrix of 784
            modules.Linear(784, 1296),
            modules.Rect(),
            modules.Linear(1296,1296),
            modules.Rect(),
            modules.Linear(1296,1296),
            modules.Rect(),
            modules.Linear(1296, 10),
            modules.SoftMax()
        ]
```

```
    ]
)

nn.train(Xtrain, Ytrain, Xtest, Ytest, batchsize=64, iters=35000, status=1000)
acc = np.mean(np.argmax(nn.forward(Xtest), axis=1) == np.argmax(Ytest, axis=1)) #classification accuracy
if not np == numpy: # np=cupy
    acc = np.asnumpy(acc)
print('model test accuracy is: {:0.4f}'.format(acc))
model_io.write(nn, '../mnist_mlp-1296-1296-1296.txt')

#try loading the model again and compute score, see if this checks out. this time in numpy
nn = model_io.read('../mnist_mlp-1296-1296-1296.txt')
acc = np.mean(np.argmax(nn.forward(Xtest), axis=1) == np.argmax(Ytest, axis=1))
if not np == numpy: acc = np.asnumpy(acc)
print('MNIST model test accuracy (numpy) is: {:0.4f}'.format(acc))

print(' XOR problem: model train accuracy is: {:0.4f}'.format(xoracc))
```

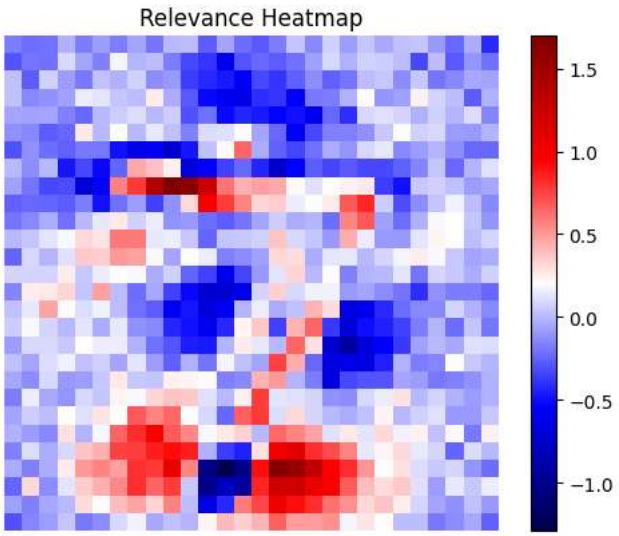
```
batch# 30800, lrate 0.005, l1-loss 0.0003907
batch# 30900, lrate 0.005, l1-loss 6.341e-05
Accuracy after 31000 iterations on validation set: 98.45% (l1-loss: 0.03388)
    Estimate time until current training ends : 0d 0h 0m 45s (88.57% done)
batch# 31100, lrate 0.005, l1-loss 0.001831
batch# 31200, lrate 0.005, l1-loss 0.02938
batch# 31300, lrate 0.005, l1-loss 6.592e-05
batch# 31400, lrate 0.005, l1-loss 7.62e-05
batch# 31500, lrate 0.005, l1-loss 8.544e-05
batch# 31600, lrate 0.005, l1-loss 0.0002249
batch# 31700, lrate 0.005, l1-loss 0.0003518
batch# 31800, lrate 0.005, l1-loss 0.0004399
batch# 31900, lrate 0.005, l1-loss 0.0006177
Accuracy after 32000 iterations on validation set: 98.42999999999999% (l1-loss: 0.03371)
    New loss-optimal parameter set encountered. saving....
    Estimate time until current training ends : 0d 0h 0m 34s (91.43% done)
batch# 32100, lrate 0.005, l1-loss 0.0004631
batch# 32200, lrate 0.005, l1-loss 6.763e-05
batch# 32300, lrate 0.005, l1-loss 0.0006857
batch# 32400, lrate 0.005, l1-loss 0.0003452
batch# 32500, lrate 0.005, l1-loss 0.0005068
batch# 32600, lrate 0.005, l1-loss 0.0009561
batch# 32700, lrate 0.005, l1-loss 0.000976
batch# 32800, lrate 0.005, l1-loss 0.0003652
batch# 32900, lrate 0.005, l1-loss 0.000852
Accuracy after 33000 iterations on validation set: 98.49% (l1-loss: 0.03381)
    Estimate time until current training ends : 0d 0h 0m 22s (94.29% done)
batch# 33100, lrate 0.005, l1-loss 0.000156
batch# 33200, lrate 0.005, l1-loss 0.000293
batch# 33300, lrate 0.005, l1-loss 9.865e-05
batch# 33400, lrate 0.005, l1-loss 0.0004425
batch# 33500, lrate 0.005, l1-loss 8.851e-05
batch# 33600, lrate 0.005, l1-loss 0.0004627
batch# 33700, lrate 0.005, l1-loss 0.0011
batch# 33800, lrate 0.005, l1-loss 6.673e-05
batch# 33900, lrate 0.005, l1-loss 0.0002134
Accuracy after 34000 iterations on validation set: 98.4% (l1-loss: 0.03441)
    Estimate time until current training ends : 0d 0h 0m 11s (97.14% done)
batch# 34100, lrate 0.005, l1-loss 0.001268
batch# 34200, lrate 0.005, l1-loss 8.277e-05
batch# 34300, lrate 0.005, l1-loss 0.0003626
batch# 34400, lrate 0.005, l1-loss 0.0005305
batch# 34500, lrate 0.005, l1-loss 0.0001638
batch# 34600, lrate 0.005, l1-loss 0.0005483
batch# 34700, lrate 0.005, l1-loss 0.0004718
batch# 34800, lrate 0.005, l1-loss 0.0006147
batch# 34900, lrate 0.005, l1-loss 0.000284
Accuracy after 35000 iterations on validation set: 98.49% (l1-loss: 0.03349)
    New loss-optimal parameter set encountered. saving....
    Estimate time until current training ends : 0d 0h 0m 0s (100.00% done)
Training terminated after 0d 0h 6m 41s
Setting network parameters to best encountered network state with 98.49% accuracy and a loss of 0.033488905344695 from iteration 3499
model test accuracy is: 0.9849
writing model as plain text to ../mnist_mlp-1296-1296-1296.txt
loading plain text model from ../mnist_mlp-1296-1296-1296.txt
MNIST model test accuracy (numpy) is: 0.9849
 XOR problem: model train accuracy is: 0.9990
```

LRP Demo MNIST

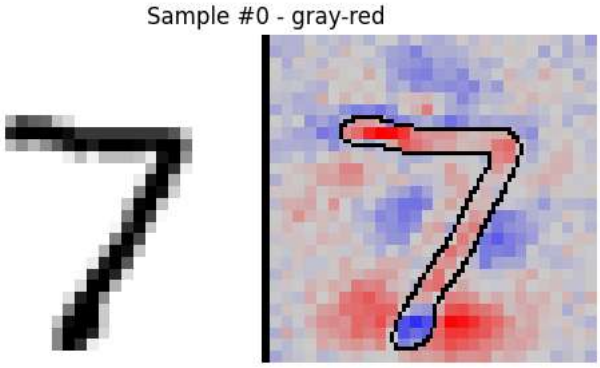
```
'''
The purpose of this module is to demonstrate the process of obtaining pixel-wise explanations for given data points at hand of the MNIST ha

The module first loads a pre-trained neural network model and the MNIST test set with labels and transforms the data such that each pixel v
The data is then randomly permuted and for the first 10 samples due to the permuted order, a prediction is computed by the network, which i
by attributing relevance values to each of the input pixels.

finally, the resulting heatmap is rendered as an image and (over)written out to disk and displayed.

LRP works by:

    Doing a standard forward pass on an input sample to make a prediction.

    Starting with the output prediction as total relevance, then propagating that relevance back layer by layer.

    At each layer, relevance is redistributed to the layer below based on specific rules (e.g., proportional to the contributions of neuron

    Finally, each input feature gets a relevance score that tells you how much it contributed to the prediction
'''


import matplotlib.pyplot as plt
import time
import numpy
import numpy as np
import importlib.util as imp
if imp.find_spec("cupy"): #use cupy for GPU support if available
    import cupy
    import cupy as np
na = np.newaxis
import render
from skimage.transform import resize


#load a neural network, as well as the MNIST test data and some labels
nn = model_io.read('../models/MNIST/long-tanh.nn') # 99.16% prediction accuracy
nn.drop_softmax_output_layer() #drop softnax output layer for analyses

X = data_io.read('../data/MNIST/test_images.npy')
Y = data_io.read('../data/MNIST/test_labels.npy')

# transfer pixel values from [0 255] to [-1 1] to satisfy the expected input / training paradigm of the model
X =  X / 127.5 - 1

# transform numeric class labels to vector indicator for uniformity. assume presence of all classes within the label set
I = Y[:,0].astype(int)
Y = np.zeros([X.shape[0],np.unique(Y).size])
Y[np.arange(Y.shape[0]),I] = 1

acc = np.mean(np.argmax(nn.forward(X), axis=1) == np.argmax(Y, axis=1))
if not np == numpy: # np=cupy
    acc = np.asnumpy(acc)
print('model test accuracy is: {:0.4f}'.format(acc))

#permute data order for demonstration. or not. your choice.
I = np.arange(X.shape[0])
#I = np.random.permutation(I)


#predict and perform LRP for the 10 first samples
for i in I[:10]:
    x = X[na,i,:]

    #forward pass and prediction
    ypred = nn.forward(x)
    print('True Class:     ', np.argmax(Y[i]))
    print('Predicted Class:', np.argmax(ypred),'\n')

    #prepare initial relevance to reflect the model's dominant prediction (ie depopulate non-dominant output neurons)
    mask = np.zeros_like(ypred)
    mask[:,np.argmax(ypred)] = 1
    Rinit = ypred*mask
```

```
    #compute first layer relevance according to prediction
    #R = nn.lrp(Rinit)                  #as Eq(56) from DOI: 10.1371/journal.pone.0130140
    R = nn.lrp(Rinit,'epsilon',0.01)    #as Eq(58) from DOI: 10.1371/journal.pone.0130140
    #R = nn.lrp(Rinit,'alphabeta',2)    #as Eq(60) from DOI: 10.1371/journal.pone.0130140

    #R = nn.lrp(ypred*Y[na,i]) #compute first layer relevance according to the true class label
    '''
    yselect = 3
    yselect = (np.arange(Y.shape[1])[na,:] == yselect)*1.
    R = nn.lrp(ypred*yselect) #compute first layer relvance for an arbitrarily selected class
    '''

    #undo input normalization for digit drawing. get it back to range [0,1] per pixel
    x = (x+1.)/2.

    if not np == numpy: # np=cupy
        x = np.asnumpy(x)
        R = np.asnumpy(R)

    #render input and heatmap as rgb images
    digit = render.digit_to_rgb(x, scaling=3)


    # Similarly, reshape the relevance map if it's flattened (1D array)
    R_numpy = R.reshape(28, 28)

    # Display the relevance map as a heatmap
    plt.imshow(R_numpy, cmap='seismic', interpolation='none')
    plt.colorbar()  # Show color bar to indicate relevance magnitude
    plt.title("Relevance Heatmap")
    plt.axis('off')
    plt.show()

    # Loop through all custom heatmaps
    for cmap_name in render.custom_maps.keys():
        print(f'Applying custom heatmap: {cmap_name}')
        hm = render.hm_to_rgb(R, X=x, scaling=3, cmap=cmap_name, sigma=2)
        digit_hm = render.save_image([digit, hm], f'../heatmap_{i}_{cmap_name}.png')

        # Display (optional)
        plt.imshow(digit_hm, interpolation='none')
        plt.title(f'Sample #{i} - {cmap_name}')
        plt.axis('off')
        plt.show()

    digit_hm = render.save_image([digit, hm], f'../heatmap_{i}.png')
    data_io.write(R,'../heatmap.npy')

    #display the image as written to file
    plt.imshow(digit_hm, interpolation = 'none')
    plt.axis('off')
    plt.show()


#note that modules.Sequential allows for batch processing inputs
if True:
    N = 256
    t_start = time.time()
    x = X[:N,...]
    y = nn.forward(x)
    R = nn.lrp(y)
    data_io.write(R,'../Rbatch.npy')
    print('Computation of {} heatmaps using {} in {:.3f}s'.format(N, np.__name__, time.time() - t_start))
```

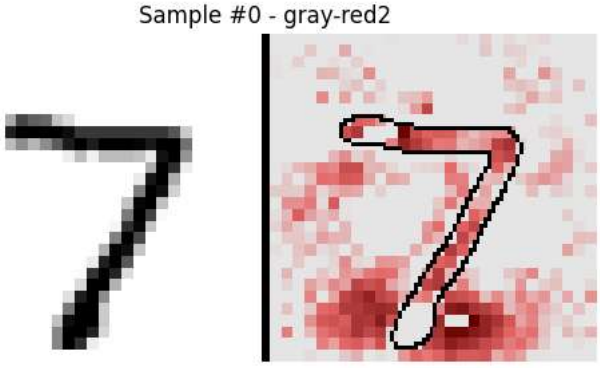
```
loading pickled model from ../models/MNIST/long-tanh.nn
removing softmax output mapping
loading np-formatted data from ../data/MNIST/test_images.npy
loading np-formatted data from ../data/MNIST/test_labels.npy
model test accuracy is: 0.9916
True Class:      7
Predicted Class: 7
```



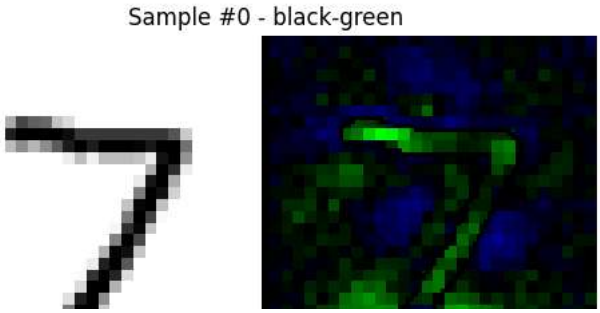

```
Applying custom heatmap: gray-red
saving image to  ../heatmap_0_gray-red.png
```



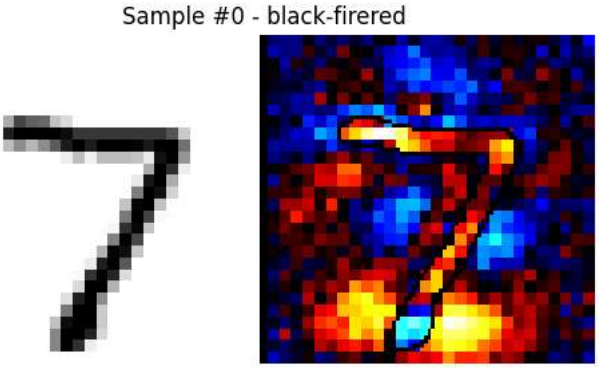

```
Applying custom heatmap: gray-red2
saving image to  ../heatmap_0_gray-red2.png
```



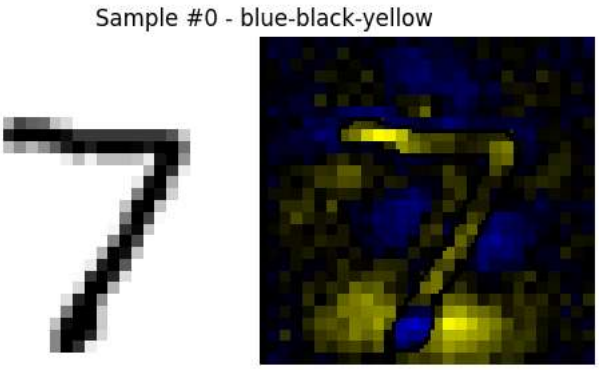

```
Applying custom heatmap: black-green
saving image to  ../heatmap_0_black-green.png
```



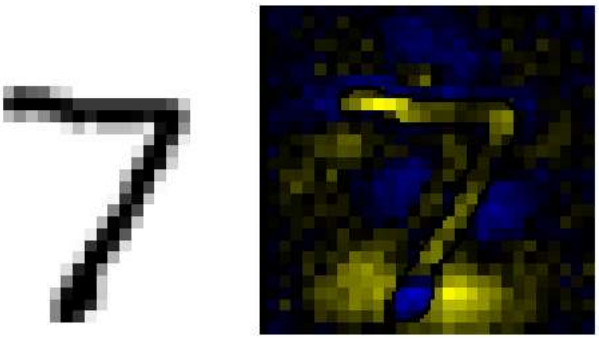
```
Applying custom heatmap: black-firered
saving image to  ../heatmap_0_black-firered.png
```



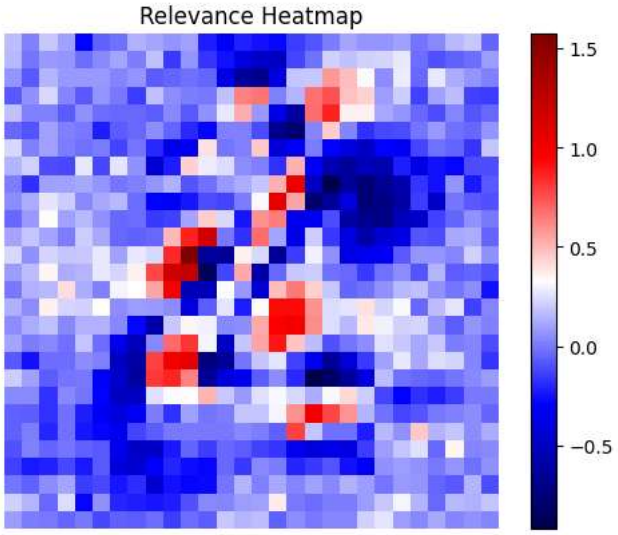

```
Applying custom heatmap: blue-black-yellow
saving image to  ../heatmap_0_blue-black-yellow.png
```




```
saving image to  ../heatmap_0.png
writing data in npy-format to ../heatmap.npy
```

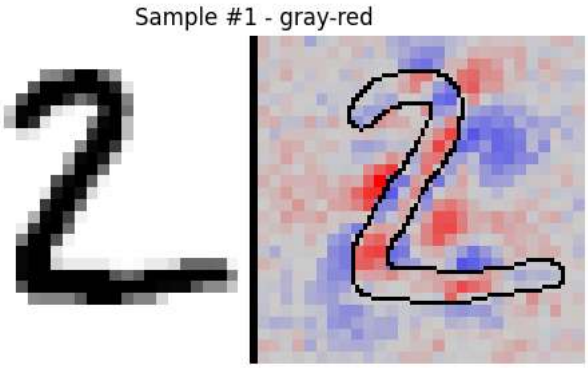


```
True Class:      2
Predicted Class: 2
```

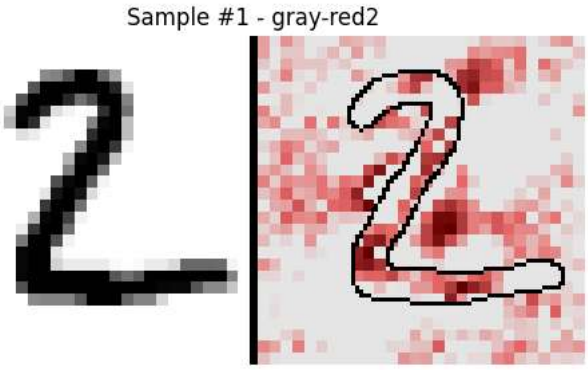



```
Applying custom heatmap: gray-red
```

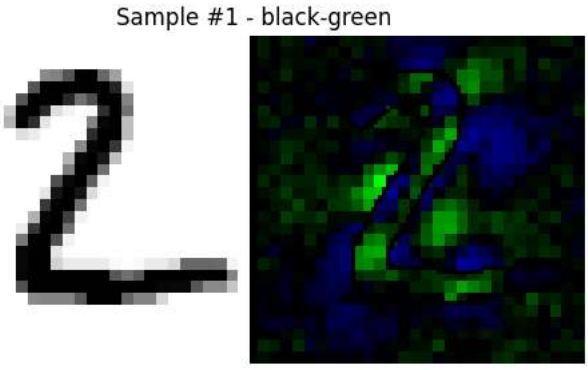
```
saving image to  ../heatmap_1_gray-red.png
```



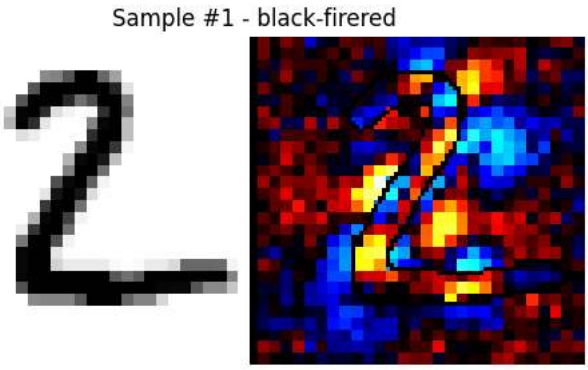

```
Applying custom heatmap: gray-red2
saving image to  ../heatmap_1_gray-red2.png
```



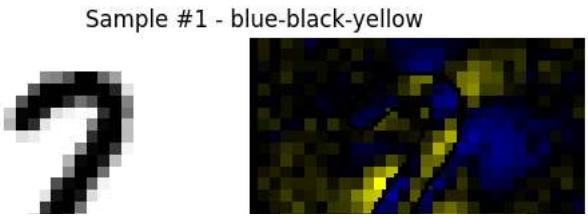

```
Applying custom heatmap: black-green
saving image to  ../heatmap_1_black-green.png
```

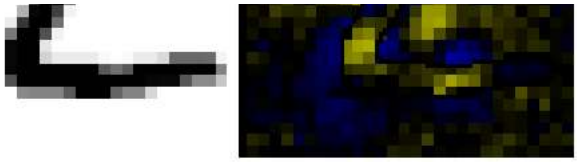



```
Applying custom heatmap: black-firered
saving image to  ../heatmap_1_black-firered.png
```

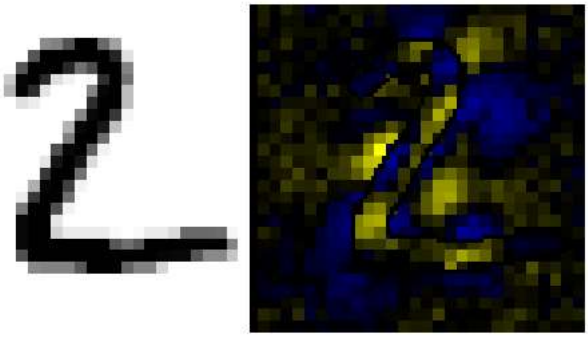



```
Applying custom heatmap: blue-black-yellow
saving image to  ../heatmap_1_blue-black-yellow.png
```

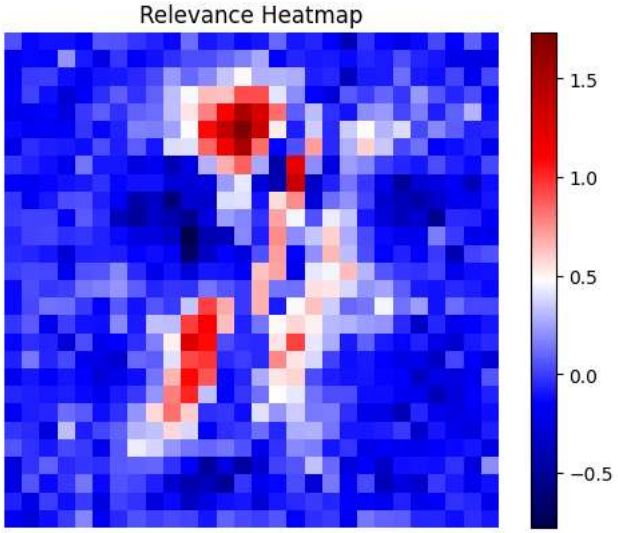




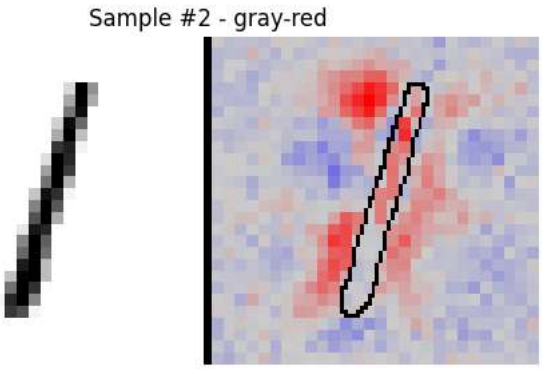
```
saving image to  ../heatmap_1.png
writing data in npy-format to ../heatmap.npy
```



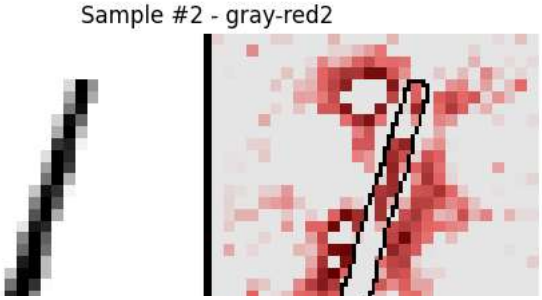
```
True Class:      1
Predicted Class: 1
```



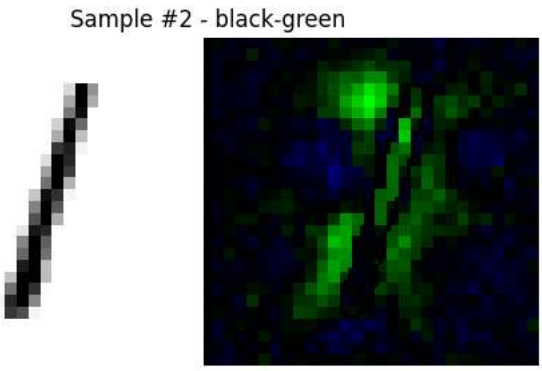

```
Applying custom heatmap: gray-red
saving image to  ../heatmap_2_gray-red.png
```



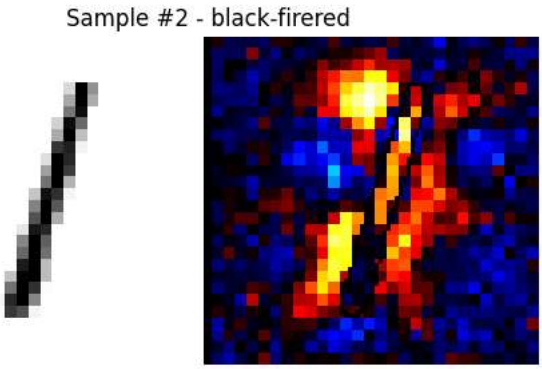

```
Applying custom heatmap: gray-red2
saving image to  ../heatmap_2_gray-red2.png
```



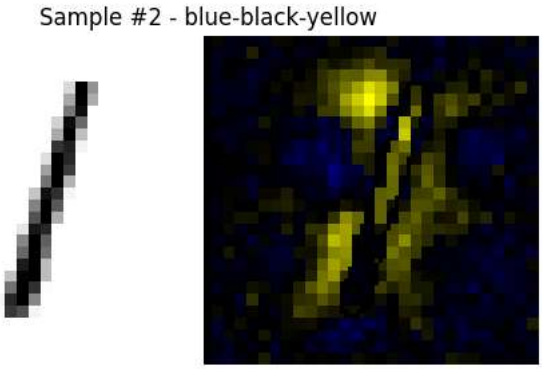
```
Applying custom heatmap: black-green
saving image to  ../heatmap_2_black-green.png
```



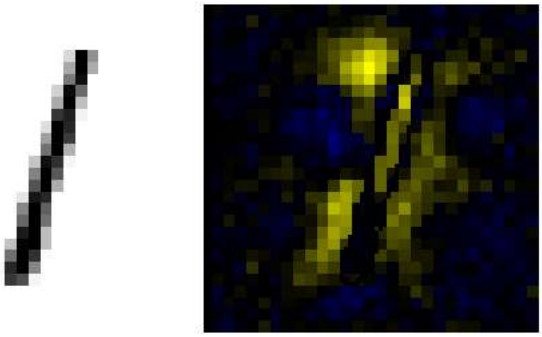

```
Applying custom heatmap: black-firered
saving image to  ../heatmap_2_black-firered.png
```



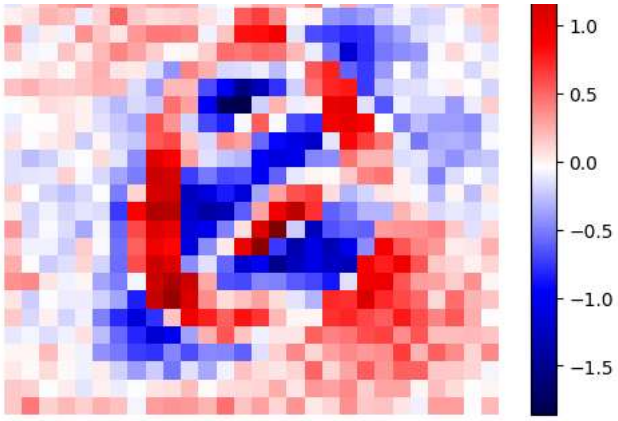

```
Applying custom heatmap: blue-black-yellow
saving image to  ../heatmap_2_blue-black-yellow.png
```




```
saving image to  ../heatmap_2.png
writing data in npy-format to ../heatmap.npy
```

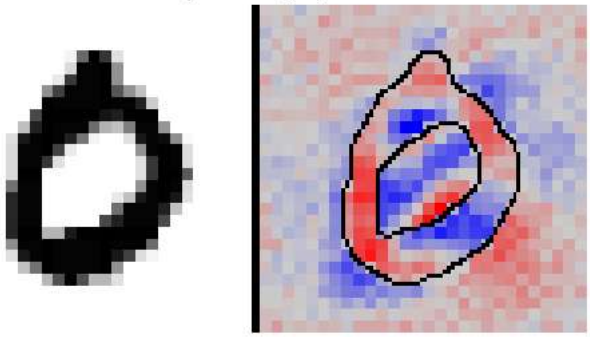


```
True Class:      0
Predicted Class: 0
```



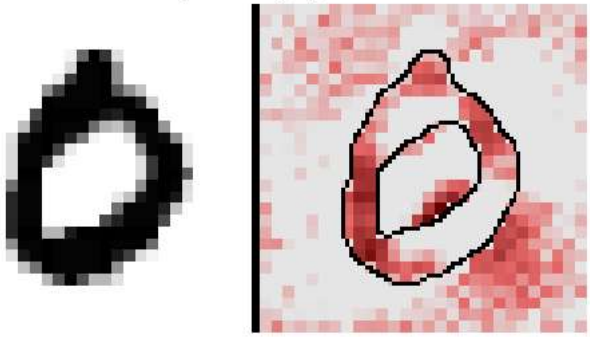

```
Applying custom heatmap: gray-red
saving image to  ../heatmap_3_gray-red.png
```

Sample #3 - gray-red



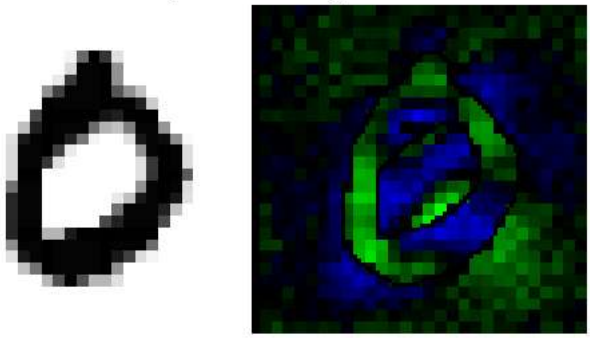
```
Applying custom heatmap: gray-red2
saving image to  ../heatmap_3_gray-red2.png
```

Sample #3 - gray-red2



```
Applying custom heatmap: black-green
saving image to  ../heatmap_3_black-green.png
```

Sample #3 - black-green



```
Applying custom heatmap: black-firered
saving image to  ../heatmap_3_black-firered.png
```

Sample #3 - black-firered