ExerciseSheet1

November 7, 2021

1 IPSA 2021 - Exercise 1

The goal of this exercise is to get used to practical image processing in *python* / *numpy* / *scipy*.

Do **NOT** use additional third party libraries such as *OpenCV* or *scikit-image* for the coding tasks in this course!

1.1 0 - Warm Up

In [1]:
```
import imageio
import numpy as np
import scipy.ndimage as img
import matplotlib.pyplot as plt

import timeit, functools
```

In [ ]:
```
!wget https://github.com/FabriceBeaumont/1-MA-INF_2314_IPSA_Repo/blob/main/Exercises/'
```

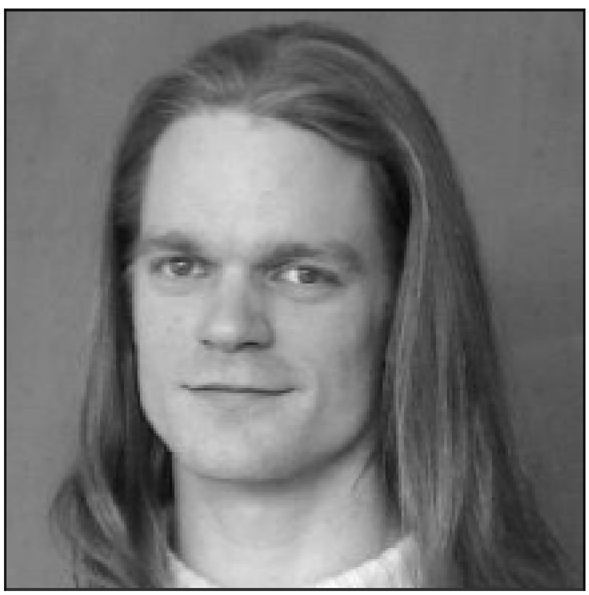
```
--2021-11-05 11:46:07--  https://github.com/FabriceBeaumont/1-MA-INF_2314_IPSA_Repo/blob/main/
Resolving github.com (github.com)... 140.82.113.4
Connecting to github.com (github.com)|140.82.113.4|:443... connected.
HTTP request sent, awaiting response... 404 Not Found
2021-11-05 11:46:07 ERROR 404: Not Found.
```

In [2]:
```
def imageRead(imgname, pilmode ='L', arrtype=np.float):
    """
    Read an image file into a numpy array

    imgname: str
        name of image file to be read
    pilmode: str
        for luminance / intesity images use L
        for RGB color images use RGB

    arrtype: numpy dtype
        use np.float, np.uint8, ...
    """
```

```
    return imageio.imread(imgname, pilmode=pilmode).astype(arrtype)

def imageWrite(arrF, imgname, arrtype=np.uint8):
    """
    Write a numpy array as an image file
    the file type is inferred from the suffix of parameter imgname, e.g. .png
    arrF: array_like
        array to be written
    imgname: str
        name of image file to be written
    arrtype: numpy dtype
        use np.uint8, ...
    """
    imageio.imwrite(imgname, arrF.astype(arrtype))
```

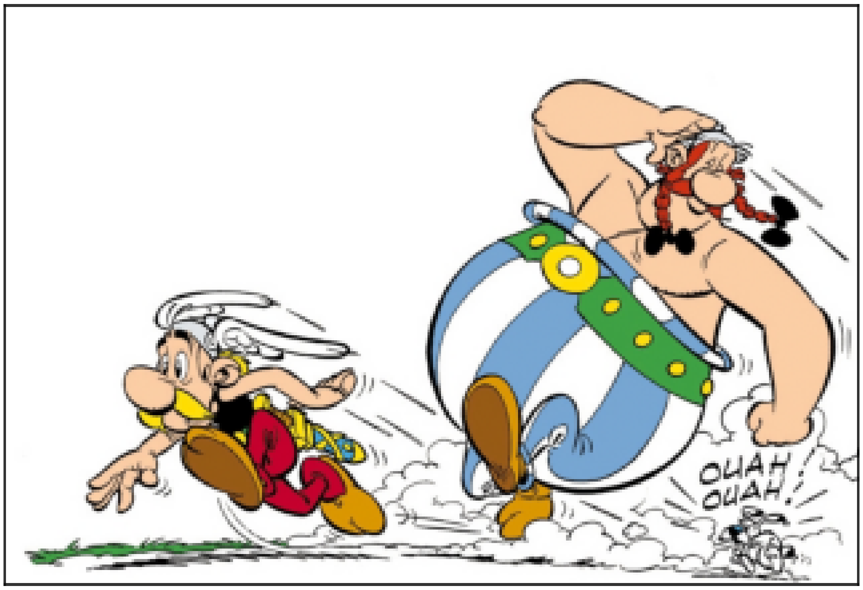
To display an intensity image use:

```
In [ ]: arrF = imageRead("portrait.png")
        plt.imshow(arrF / 255, cmap='gray')
        plt.xticks([]); plt.yticks([])
        plt.show()
```



To display an (RGB) color image use:

```
In [ ]: arrF = imageRead('asterixRGB.png', pilmode='RGB')
        plt.imshow(arrF / 255)
        plt.xticks([]); plt.yticks([])
        plt.show()
```



1.2 1 - The emboss effect

```
In [48]: filename = "portrait.png"

         arrF = imageRead(filename)
         print(f"The image '{filename}' has {arrF.shape[0]} rows and {arrF.shape[1]} columns.")
```

```
The image 'portrait.png' has 256 rows and 256 columns.
```

1.2.1 Different emboss implementations

```
In [49]: def embossV1(arrF):
             """
             Naive Emboss: Iterate through all cells and explicitly compute the
             every gradient. Do so by computing the difference between the intensity
             values in the lower right and upper left cell.
             Add 255/2 = 128 to compensate for the induced value shift.
             Clip the results to the interval [0, 255].

             Slow implementation.
             """
             M, N = arrF.shape
             arrG = np.zeros((M,N))

             for i in range(1,M-1):
                 for j in range(1,N-1):
```

```python
            arrG[i,j] = 128 + arrF[i+1,j+1] - arrF[i-1,j-1]
            arrG[i,j] = np.maximum(0, np.minimum(255, arrG[i,j]))

    return arrG
```

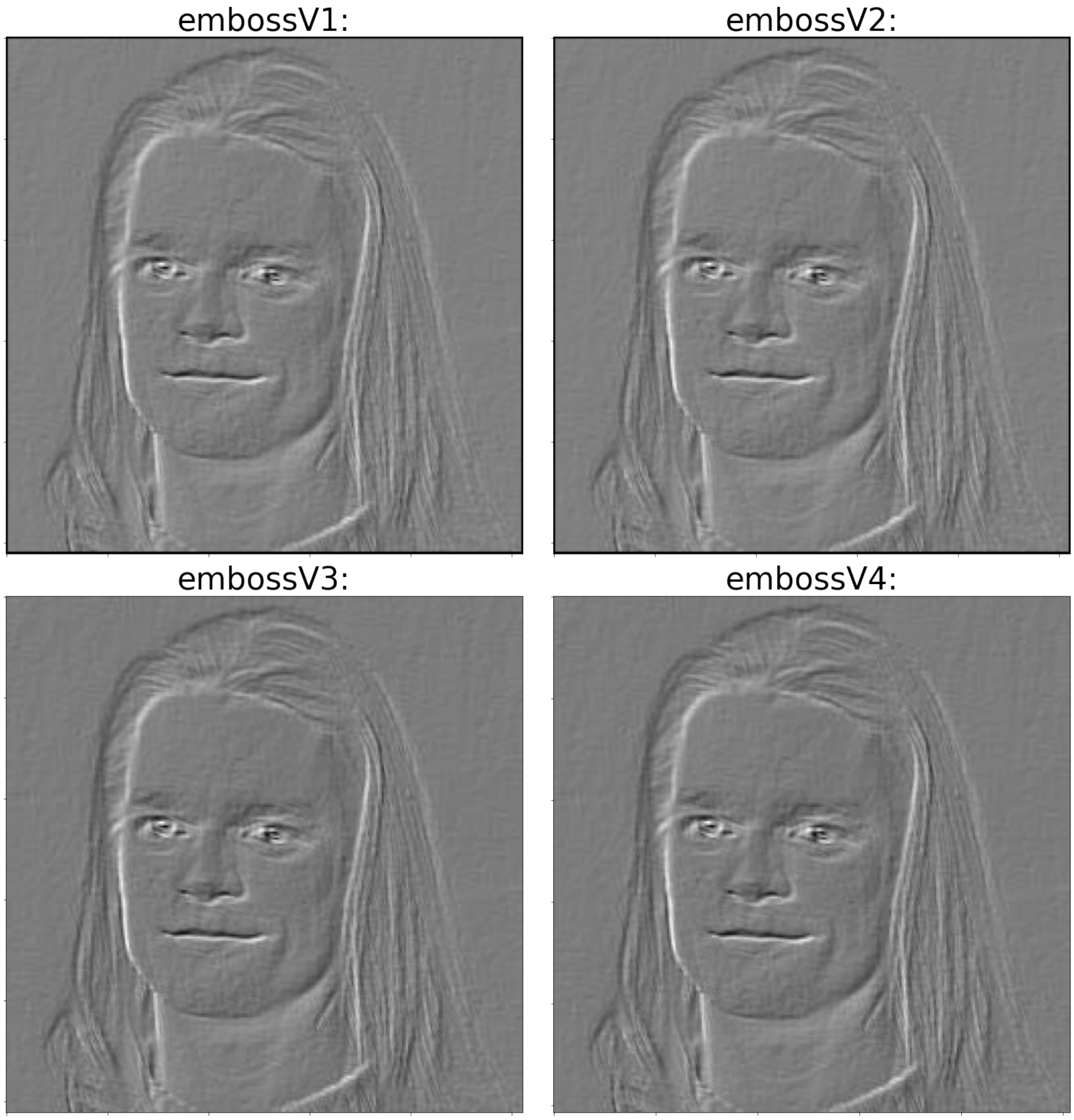
In [50]:
```python
def embossV2(arrF):
    """
    Numpythonic Emboss: Use python-slicing to compute all gradients
    at once by subtracting the upper left (M-2 x N-2)-matrix
    from the lower right (M-2 x N-2)-matrix - to yield the gradients
    of the central (M-1 x N-1)-matrix.
    Add 255/2 = 128 to compensate for the induced value shift.
    Clip the results to the interval [0, 255].

    Fast implementation.
    """
    M, N = arrF.shape
    arrG = np.zeros((M,N))

    arrG[1:M-1,1:N-1] = 128 + arrF[2:,2:] - arrF[:-2,:-2]
    arrG = np.maximum(0, np.minimum(255, arrG))

    return arrG
```

In [51]:
```python
def embossV3(arrF):
    """
    Convolution Emboss: similar to CNNs, use a 3x3-mask which sweeps
    over all non-border-cells.
    Add 255/2 = 128 to compensate for the induced value shift.
    Clip the results to the interval [0, 255].

    Fast and practival (generalizable) implementation.
    """
    mask = np.array([[-1, 0,  0],
                     [ 0, 0,  0],
                     [ 0, 0, +1]])

    arrG = 128 + img.correlate(arrF, mask, mode='reflect')
    arrG = np.maximum(0, np.minimum(255, arrG))

    return arrG
```

In [69]:
```python
def embossV4(arrF):
    """
    Numpythonic Emboss: Use python-slicing to compute all gradients
    at once by subtracting the upper left (M-1 x N-1)-matrix
    from the lower right (M-1 x N-1)-matrix - to yield the gradients
    of the central (M-1 x N-1)-matrix. Notice, that only this matrix is stored,
```

```
    thus the dimensions are diminished in each direction by two and no black
    boreder will remain.

    Add 255/2 = 128 to compensate for the induced value shift.

    Clip the results to the interval [0, 255], by using
    pythons array boolean indexing. (Masks for the corner values.)
    """
    arrG = 128 + arrF[2:,2:] - arrF[:-2,:-2]
    arrG[arrG<  0] =   0
    arrG[arrG>255] = 255

    return arrG
```

In [70]:
```
methods = [embossV1, embossV2, embossV3, embossV4]
arrGs = [arrF] * len(methods)

fig, axs = plt.subplots(int(0.5*len(methods)), 2, figsize=(20,20))

for i, mtd in enumerate(methods):
    arrGs[i] = mtd(arrF)

    ax = axs[int(i/2), i%2]
    ax.imshow(arrGs[i], cmap='gray')
    ax.set_title(f"{mtd.__name__}:", fontsize=40)
    ax.set_xticklabels([]); ax.set_yticklabels([])
    fig.tight_layout()
```



Notice that method `embossV3` and `embossV4` do not result in a black border.
Furthermore notice, how `embossV3` does not trimm the image:

```
In [68]: for i, arrG in enumerate(arrGs):
             print(f"Image dimensions when using method embossV{i}: {arrG.shape}")
             print("\tDoes %screate a black border.\n\n"%("not " if arrG[0][100] != 0 else ""))
```

```
Image dimensions when using method embossV0: (256, 256)
        Does create a black border.


Image dimensions when using method embossV1: (256, 256)
        Does create a black border.
```

```
Image dimensions when using method embossV2: (256, 256)
        Does not create a black border.


Image dimensions when using method embossV3: (254, 254)
        Does not create a black border.
```

1.3 2 - Timing the emboss effect

1.3.1 2 a)

```
In [ ]: def runtime_evaluation(data, methods, nRep, nRun):
            print("Mean runtimes for:")
            for method in methods:
                ts = timeit.Timer(functools.partial(method, data)).repeat(nRep, nRun)
                print(f"{method.__name__}:\t{min(ts) / nRun}\t[sec]")
```

```
In [ ]: mtds = [embossV1, embossV2, embossV3, embossV4]
        nRep = 3
        nRun = 100
```

```
In [ ]: filename0 = "portrait.png"
        arrF0 = imageRead(filename0)

        runtime_evaluation(arrF0, methods, nRep, nRun)
```

```
Mean runtimes for:
embossV1:        0.29045785174999766        [sec]
embossV2:        0.0006378255400022681        [sec]
embossV3:        0.000883353970002645        [sec]
embossV4:        0.00031468285000300965        [sec]
```

1.3.2 2 b)

```
In [ ]: filename1 = "asterix.png"
        arrF1 = imageRead(filename1)

        runtime_evaluation(arrF1, methods, nRep, nRun)
```

```
Mean runtimes for:
embossV1:        1.646454750269995        [sec]
embossV2:        0.0034446558699983143        [sec]
embossV3:        0.004903635989994655        [sec]
embossV4:        0.0020958068999971146        [sec]
```

1.3.3 2 c)

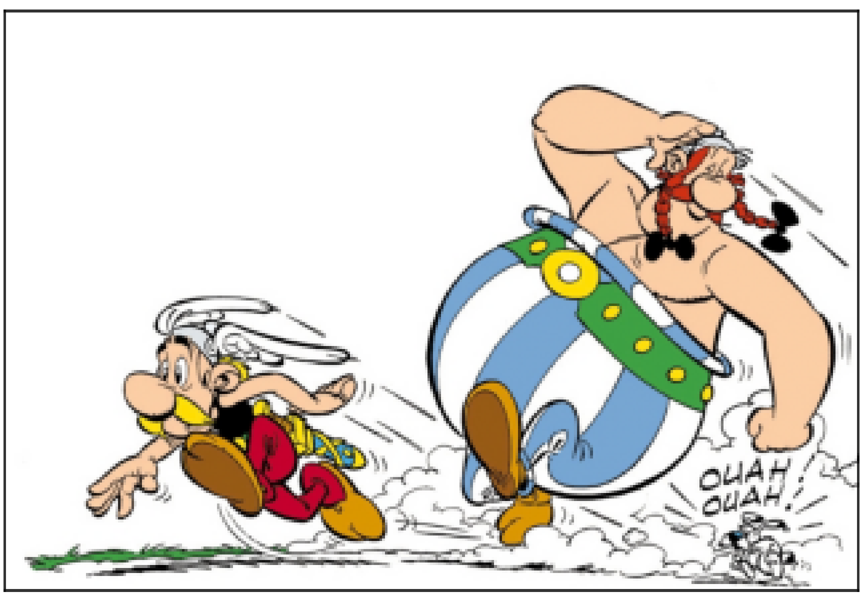
```
In [ ]: n0, m0 = arrF0.shape
        n1, m1 = arrF1.shape
        print(f"The image '{filename0}' has dimensions {n0}x{m0} and thus {n0*m0} cells.")
        print(f"The image '{filename1}' has dimensions {n1}x{m1} and thus {n1*m1} cells.")
        print(f"That is almost {round(n1*m1/(n0*m0))}-times as much!")
        print(f"This corresponds to the increase in runtime, approximately linear wrt to the nu
```

```
The image 'portrait.png' has dimensions 256x256 and thus 65536 cells.
The image 'asterix.png' has dimensions 496x730 and thus 362080 cells.
That is almost 6-times as much!
This corresponds to the increase in runtime, approximately linear wrt to the number of cells.
```

1.4 3 - Working with RGB color images

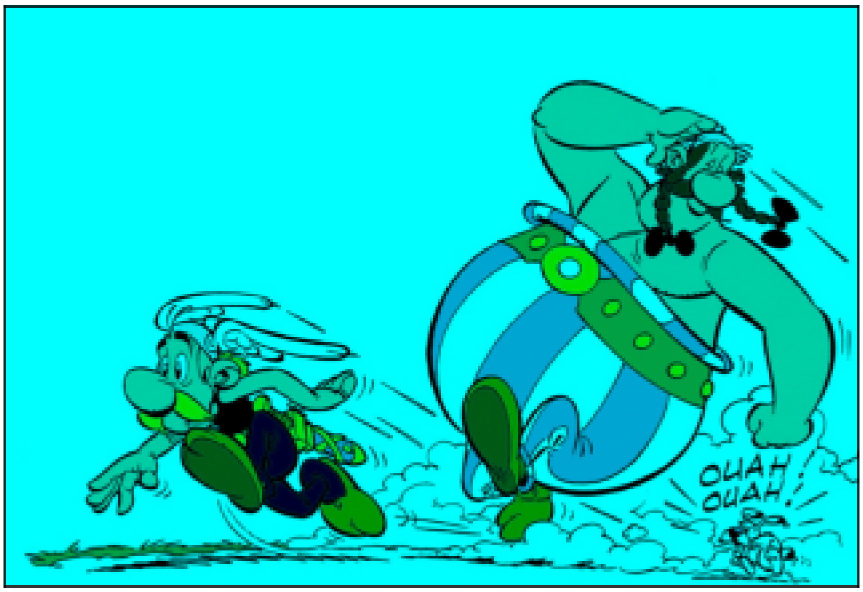
```
In [ ]: arrF = imageRead('asterixRGB.png', pilmode='RGB')

        print(arrF.shape)
        plt.imshow(arrF / 255)
        plt.xticks([]); plt.yticks([])
        plt.show()
```

```
(496, 730, 3)
```



```
In [ ]: arrG = np.copy(arrF)
        arrG[:,:,0] = 0

        print(arrG.shape)
        plt.imshow(arrG / 255)
        plt.xticks([]); plt.yticks([])
        plt.show()
```

```
(496, 730, 3)
```



We can see, that all values of the third RGB-channel were set to zero. Thus the **image does no longer contain the color red**. Red is replaced by black.

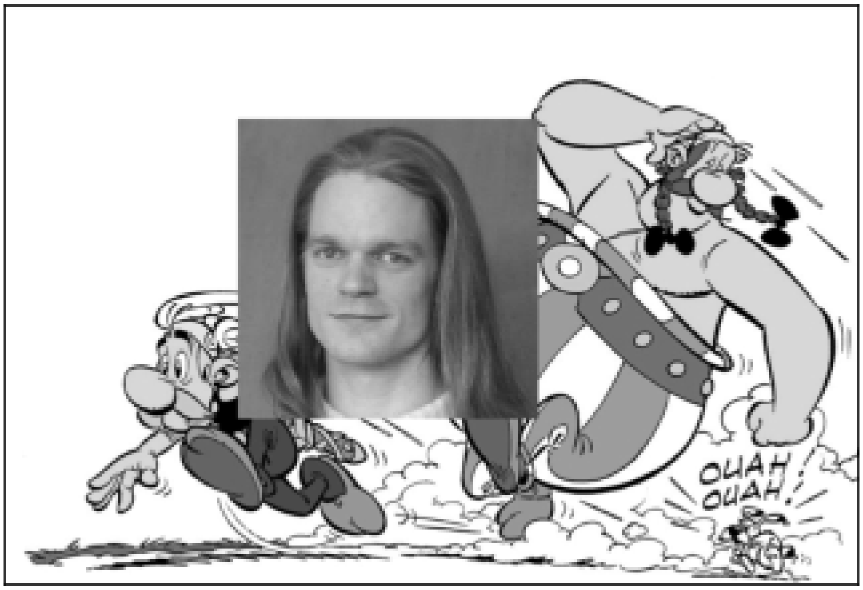
Notice that asterix's trousers are black. And the white background is only composed out of the colors green and blue.

Explanation of the code `arrG[:,:,0] = 0` operates on all cells (`[:,:]`) and the first (zeroth) of the color channels (which are stored in the thrid position. Thus the red-value for every pixel is set to zero/black.

1.5 4 - Getting used to slicing (part 1)

```
In [ ]: arrF = imageRead('asterix.png')
        arrG = imageRead('portrait.png')

        arrH = np.copy(arrF)
        n, m = arrG.shape

        i, j = 100, 200
        arrH[i:i+n,j:j+m] = arrG
```

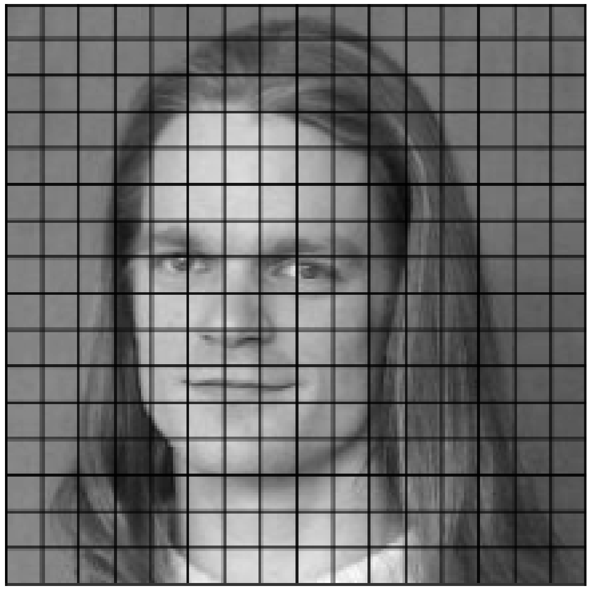
```
In [ ]: plt.imshow(arrH / 255, cmap='gray')
        plt.xticks([]); plt.yticks([])
        plt.show()
```



1.6 5 - Getting used to slicing (part 2)

```
In [ ]: arrF = imageRead('portrait.png')
        n, m = arrF.shape
        d = 16
        arrF[:,::d] = 0
        arrF[::d,:] = 0
```

```
In [ ]: plt.imshow(arrF / 255, cmap='gray')
        plt.xticks([]); plt.yticks([])
        plt.show()
```



1.7 6 - Getting used to meshgrids (part 1)

```
In [ ]: arrF = imageRead('portrait.png')
        n, m = arrF.shape
        width_offset = 50
        height_offset = 85
        ci, cj = 128, 110
```

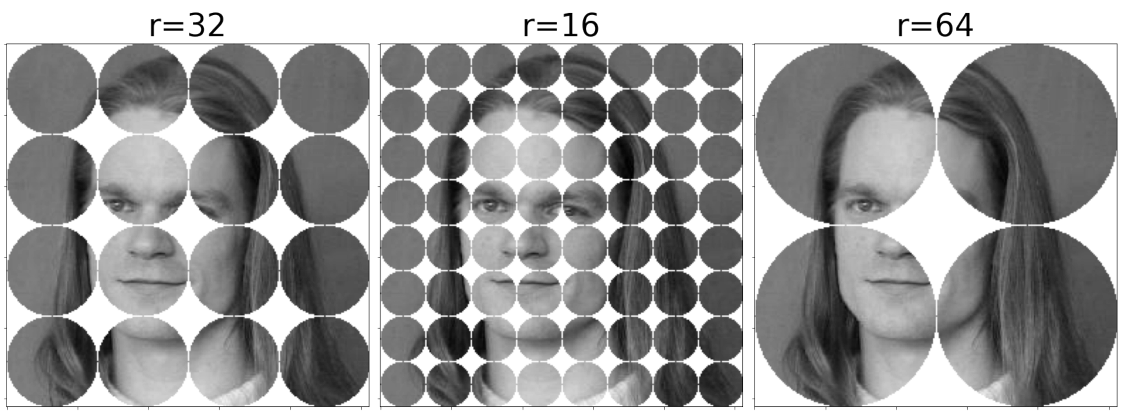
```
In [ ]: # Use meshgrid to create an index mask.
        rs, cs = np.meshgrid(np.arange(m), np.arange(n), indexing='ij')

        # For the ellipse use a similar formula like the unit circle
        # Simply offset the origin by the defined center, and
        # scale the height (y-axis) and width (x-axis) differently.
        mask = ((rs-ci)**2 / height_offset**2 + (cs-cj)**2 / width_offset**2  <= 1)

        # Apply the change to the image - in the area of the mask.
        arrF[mask] = 255
```

```
In [ ]: plt.imshow(arrF / 255, cmap='gray')
        plt.xticks([]); plt.yticks([])
        plt.show()
```

1.8 7 - Getting used to meshgrids (part 2)

```
In [45]: arrF = imageRead('portrait.png')
         n, m = arrF.shape
         radii = [32, 16, 64]

In [46]: def circle_cutouts(arrF, r=32):
             m, n = arrF.shape

             # Create a meshgrid for only one circle (with diameter 2*r).
             rs, cs = np.meshgrid(np.arange(2*r), np.arange(2*r), indexing='ij')

             # Define the circle cutout.
             # Notice that the OUTSIDE of the circle is masked ('>').
             mask = ((rs-r)**2 + (cs-r)**2 > r**2)

             # Tile the circle as often as it fits in the dimensions
             mask = np.tile(mask, (m//(2*r), n//(2*r)))

             # Apply the mask
             arrG = np.copy(arrF)
             arrG[mask] = 255

             return arrG

In [ ]: fig, axs = plt.subplots(1, 3, figsize=(20,20))
```

```
    for i, radius in enumerate(radii):

        arrG = circle_cutouts(arrF, r=radius)

        ax = axs[i]
        ax.imshow(arrG, cmap='gray')
        ax.set_title(f"r={radius}", fontsize=35)
        ax.set_xticklabels([]); ax.set_yticklabels([])
        fig.tight_layout()
```



Runtime measurements

In [47]:
```
nRep =   3
nRun = 100
ts = timeit.Timer(functools.partial(circle_cutouts, arrF)).repeat(nRep, nRun)
print(f"{min(ts) / nRun} [sec]")
```

```
0.00025478838999788423 [sec]
```

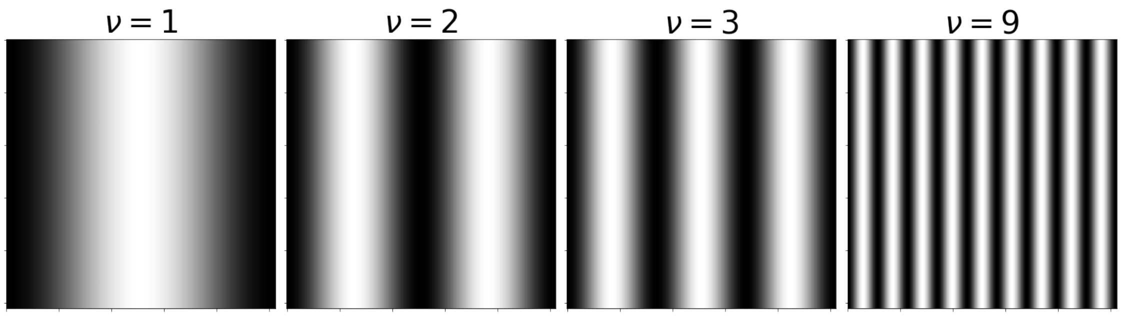
In [ ]:
```
# TODO: Evaluate runtime complexity
```

1.9 8 - Getting used to meshgrids (part 3)

In [12]:
```
m = n = 256


def sin_func(x, y, nu, n):
    sinus_term = np.sin(2 * np.pi * nu * x / (n-1) + np.pi / 2 * (n-1))
    return 0.5 * (sinus_term + 1) * 255
```

In [43]:
```
xs, ys = np.meshgrid(np.arange(n), np.arange(m))
```

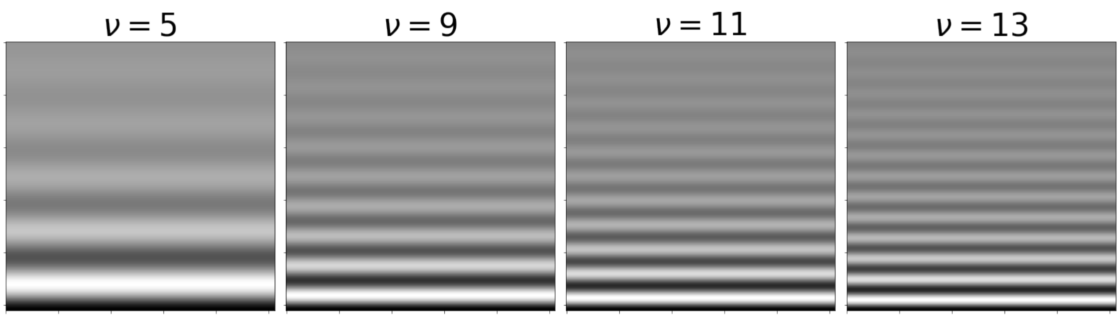
```
In [32]: nu_list = [1., 2., 3., 9.]

         fig, axs = plt.subplots(1, len(nu_list), figsize=(20,20))

         for i, nu in enumerate(nu_list):
             arrF = sin_func(xs, ys, nu, n)

             ax = axs[i]
             ax.imshow(arrF, cmap='gray')
             ax.set_title(r"$\nu=$%i"%nu, fontsize=40)
             ax.set_xticklabels([]); ax.set_yticklabels([])
             fig.tight_layout()
```



1.10 9 - Getting used to meshgrids (part 4)

```
In [31]: def dampedVerticalSineWave(M, N, nu):
             xs, ys = np.meshgrid(np.arange(N), M-1-np.arange(M))
             return 0.5 * (np.exp(-4 / M * ys) * np.sin(2 * np.pi * nu * ys / (M-1) + np.pi /
```

```
In [33]: nu_list = [5., 9., 11., 13.]

         fig, axs = plt.subplots(1, len(nu_list), figsize=(20,20))

         for i, nu in enumerate(nu_list):
             arrF = dampedVerticalSineWave(256, 256, nu)

             ax = axs[i]
             ax.imshow(arrF, cmap='gray')
             ax.set_title(r"$\nu=$%i"%nu, fontsize=40)
             ax.set_xticklabels([]); ax.set_yticklabels([])
             fig.tight_layout()
```



1.11 10 - Getting used to universal functions

```
In [34]: def solarize(arrF, nu):
             return np.cos(arrF * nu * 2 * np.pi / 255.) * 127.5 + 127.5
```

```
In [42]: nu_list = [0.5, 1.0, 1.5, 2.0]

         fig, axs = plt.subplots(1, len(nu_list), figsize=(20,20))
         arrF = imageRead('portrait.png')

         for i, nu in enumerate(nu_list):
             arrG = solarize(arrF, nu)

             ax = axs[i]
             ax.imshow(arrG, cmap='gray')

             ax.set_title(r"$\nu=$"+ f"{nu:.1f}", fontsize=40)
             ax.set_xticklabels([]); ax.set_yticklabels([])
             fig.tight_layout()
```