
MEAutility Documentation

Release 1.2.1

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Python package for multi-electrode array (MEA) handling and stimulation.

CHAPTER 1

Installation

To install run:

```
pip install MEAutility
```

If you want to install from sources and be updated with the latest development you can install with:

```
git clone https://github.com/alejoe91/MEAutility  
cd MEAutility  
python setup.py install (or develop)
```

The package can then be imported in Python with:

```
import MEAutility as MEA
```


CHAPTER 2

Requirements

- numpy
- pyyaml
- matplotlib

The following sections will guide you through definitions and handling of MEA models, as well as electrical stimulation and plotting functions.

3.1 MEA definition

This notebook shows how MEA can be using a .yaml file and how MEA models can be added and removed to and from the file system.

3.1.1 List available MEAs:

```
MEA.return_mea()
```

Available MEA:

```
['SqMEA-6-25um', 'SqMEA-10-15um', 'tetrode', 'Neuroseeker-128', 'SqMEA-5-30um',  
↪ 'SqMEA-15-10um', 'Neuronexus-32-Kampff', 'Neuronexus-32-cut-30', 'Neuropixels-128',  
↪ 'Neuroseeker-128-Kampff', 'Neuropixels-24', 'SqMEA-7-20um', 'Neuronexus-32',  
↪ 'Neuropixels-384']
```

These MEA are saved during installation. Each MEA corresponds to a .yaml file containing key information for the MEA. Let's take a look at some examples.

3.1.2 Square MEA

```
sqmea_info = MEA.return_mea_info('SqMEA-10-15um')  
pprint(sqmea_info)
```

```
{'dim': 10,  
'electrode_name': 'SqMEA-10-15um',  
'pitch': 15,  
'shape': 'square',  
'size': 5,  
'sortlist': None,  
'type': 'mea'}
```

The returned dictionary corresponds to the .yaml file. For this MEA model `dim` is a single `int` and `pitch` is a single `int` (or `float`). Therefore, a 10x10 Square MEA is instantiated with 15um pitch in the yz direction (if `plane` is not in the yaml file, yz is default). The electrodes shape is square, and half the side length is 5um. Since `sortlist` is `None`, the electrode count starts from the bottom left and it follows the rows up and then goes to the next column (the last index is the electrode on the top right). The `type` `mea` will be used for plotting.

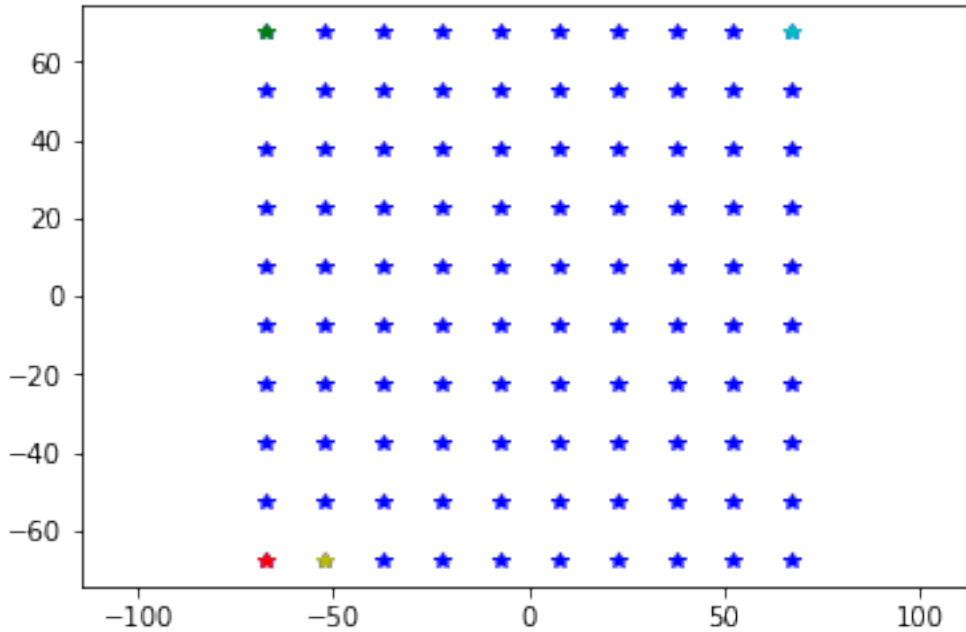
Let's now instantiate a MEA object:

```
sqmea = MEA.return_mea('SqMEA-10-15um')  
print(type(sqmea))  
print(sqmea.number_electrodes)  
print(sqmea.dim)
```

```
'plane' field with 2D dimensions assumed to be 'yz'  
Model is set to semi  
<class 'MEAutility.core.RectMEA'>  
100  
[10, 10]
```

The MEA is a rectangular MEA with 100 electrodes.

```
plt.plot(sqmea.positions[:, 1], sqmea.positions[:, 2], 'b*')  
plt.plot(sqmea.positions[0, 1], sqmea.positions[0, 2], 'r*')  
plt.plot(sqmea.positions[9, 1], sqmea.positions[9, 2], 'g*')  
plt.plot(sqmea.positions[10, 1], sqmea.positions[10, 2], 'y*')  
plt.plot(sqmea.positions[-1, 1], sqmea.positions[-1, 2], 'c*')  
_ = plt.axis('equal')
```



Rectangular MEAs can be handled as matrices, where the first index is the ROW and the second index is the COLUMN:

```
print(sqmea[0][0].position) # electrode 0
print(sqmea[9][0].position) # electrode 9
print(sqmea[0][1].position) # electrode 10
print(sqmea[-1][-1].position) # electrode 99
```

```
[ 0. -67.5 -67.5]
[ 0. -67.5  67.5]
[ 0. -52.5 -67.5]
[ 0.  67.5  67.5]
```

3.1.3 Rectangular MEA

```
neuroseeker_info = MEA.return_mea_info('Neuroseeker-128')
pprint(neuroseeker_info)
```

```
{'dim': [32, 4],
 'electrode_name': 'Neuroseeker-128',
 'pitch': 22.5,
 'shape': 'square',
 'size': 10.0,
 'sortlist': None,
 'type': 'mea'}
```

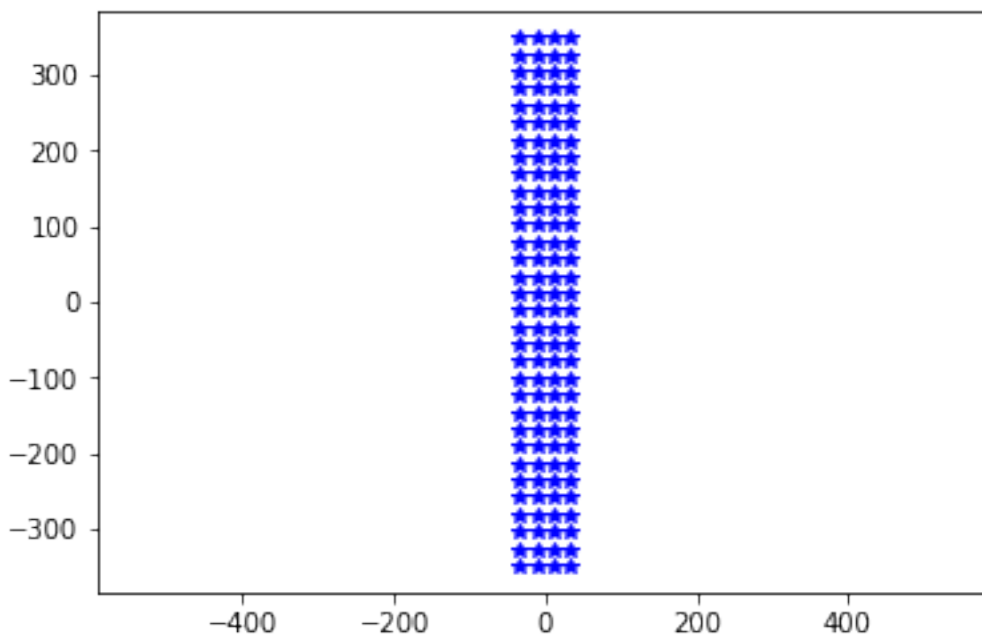
This MEA is rectangular, with 32 rows, 4 columns, and a regular pitch of 22.5um

```
neuroseeker = MEA.return_mea('Neuroseeker-128')
print(type(neuroseeker))
print(neuroseeker.number_electrodes)
print(neuroseeker.dim)
```

```
'plane' field with 2D dimensions assumed to be 'yz'
Model is set to semi
<class 'MEAutility.core.RectMEA'>
128
[32, 4]
```

```
plt.plot(neuroseeker.positions[:, 1], neuroseeker.positions[:, 2], 'b*')
_ = plt.axis('equal')
print(neuroseeker[0][0].position) # electrode 0
print(neuroseeker[31][0].position) # electrode 31
print(neuroseeker[1][0].position) # electrode 32
print(neuroseeker[-1][-1].position) # electrode 127
```

```
[ 0.   -33.75 -348.75]
[ 0.   -33.75  348.75]
[ 0.   -33.75 -326.25]
[ 0.    33.75  348.75]
```



3.1.4 General MEA

When `dim` and `pitch` are single `int` (or `float` for `pitch`) or a list of 2 values, a rectangular MEA is created. Some MEA configuration can be different.

```
neuronexus_info = MEA.return_mea_info('Neuronexus-32')
pprint(neuronexus_info)
```

```
{'dim': [10, 12, 10],
 'electrode_name': 'Neuronexus-32',
 'pitch': [25.0, 18.0],
 'shape': 'circle',
 'size': 7.5,
```

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```
'sortlist': None,
'stagger': -12.5,
'type': 'mea'}
```

For this MEA there are 3 different options: - `dim` has 3 elements - `pitch` has 2 elements - `stagger` is present

When `len(dim) > 2`, then each element represents the number of rows of each column. In this case, there are 3 columns: the first and third have 10 electrodes, the second one has 12.

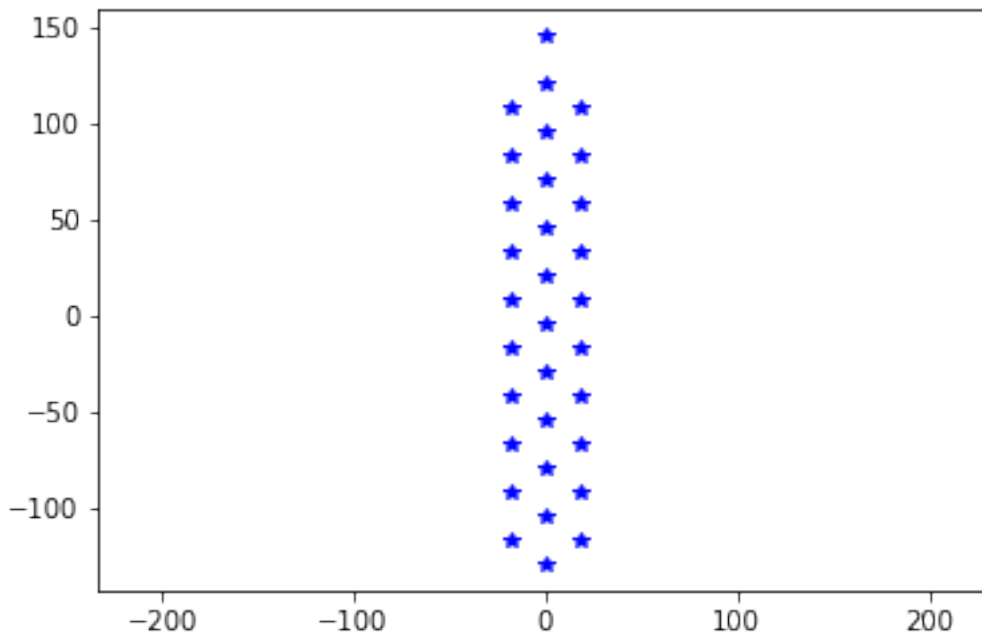
The first value of `pitch` is the inter-row distance (top to bottom). The second value is the inter-column distance (left to right).

The `stagger` key allows the shift columns. If only one value is given (int or float) every other column starting from the second one is staggered. Otherwise `stagger` can be a list with the same number of elements of `dim`.

Given this information, we can expect how the neuronexus MEA looks like:

```
neuronexus = MEA.return_mea('Neuronexus-32')
plt.plot(neuronexus.positions[:, 1], neuronexus.positions[:, 2], 'b*')
_ = plt.axis('equal')
```

'plane' field with 2D dimensions assumed to be 'yz'
Model is set to semi



Adding and removing MEA models

It is possible to load user-defined yaml files in the MEAutility package, so that they are available from the entire file system.

Let's first create a `user.yaml` file on-the-fly.

```
import yaml, os

user_info = {'dim': [10, 12, 9, 8],
             'electrode_name': 'user',
             'description': "a brief description of the probe",
             'pitch': [10.0, 40.0],
             'shape': 'circle',
             'size': 7.5,
             'sortlist': None,
             'stagger': [0, -12, 30, -22],
             'type': 'mea'}

with open('user.yaml', 'w') as f:
    yaml.dump(user_info, f)

yaml_files = [f for f in os.listdir('.') if f.endswith('.yaml')]
print(yaml_files)
```

```
['user.yaml']
```

Now we can add the newly created yaml file to the MEA package:

```
MEA.add_mea('user.yaml')
```

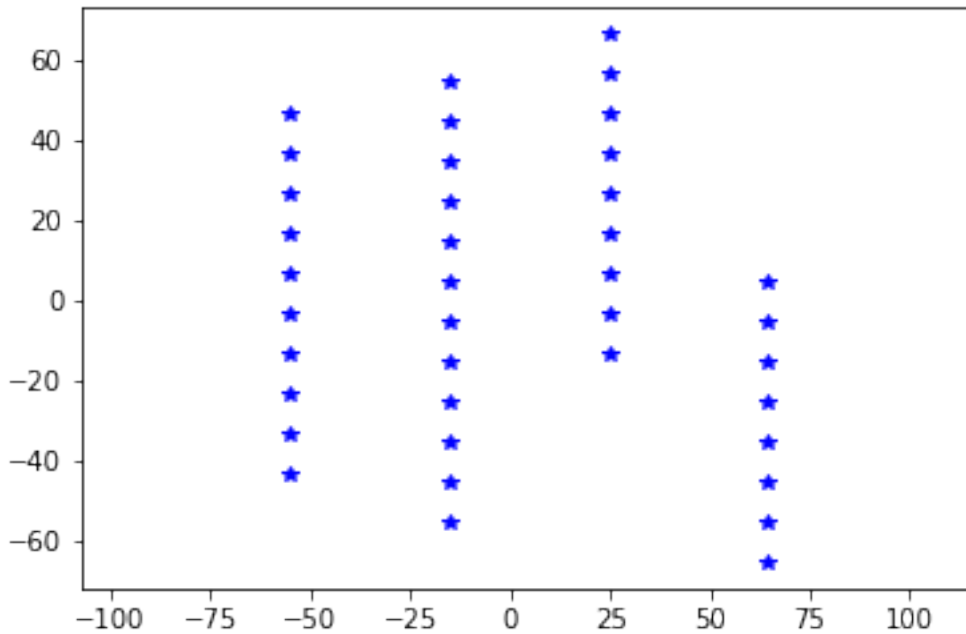
Available MEA:

```
['SqMEA-6-25um', 'SqMEA-10-15um', 'tetrode', 'Neuroseeker-128', 'SqMEA-5-30um',
→ 'SqMEA-15-10um', 'Neuronexus-32-Kampff', 'Neuronexus-32-cut-30', 'Neuropixels-128',
→ 'Neuroseeker-128-Kampff', 'Neuropixels-24', 'SqMEA-7-20um', 'Neuronexus-32', 'user',
→ 'Neuropixels-384']
```

and create a user MEA object:

```
usermea = MEA.return_mea('user')
plt.plot(usermea.positions[:, 1], usermea.positions[:, 2], 'b*')
_ = plt.axis('equal')
```

```
'plane' field with 2D dimensions assumed to be 'yz'
Model is set to semi
```



If we don't need the user MEA anymore, we can remove it from the MEA package:

```
MEA.remove_mea('user')
```

```
Removed: /home/alessiob/anaconda3/envs/mearec/lib/python3.6/site-packages/MEAutility/
↳ electrodes/user.yaml
Available MEA:
['SqMEA-6-25um', 'SqMEA-10-15um', 'tetrode', 'Neuroseeker-128', 'SqMEA-5-30um',
↳ 'SqMEA-15-10um', 'Neuronexus-32-Kampff', 'Neuronexus-32-cut-30', 'Neuropixels-128',
↳ 'Neuroseeker-128-Kampff', 'Neuropixels-24', 'SqMEA-7-20um', 'Neuronexus-32',
↳ 'Neuropixels-384']
```

3.2 MEA handling

This notebook shows how to handle MEA and electrodes in the 3D space.

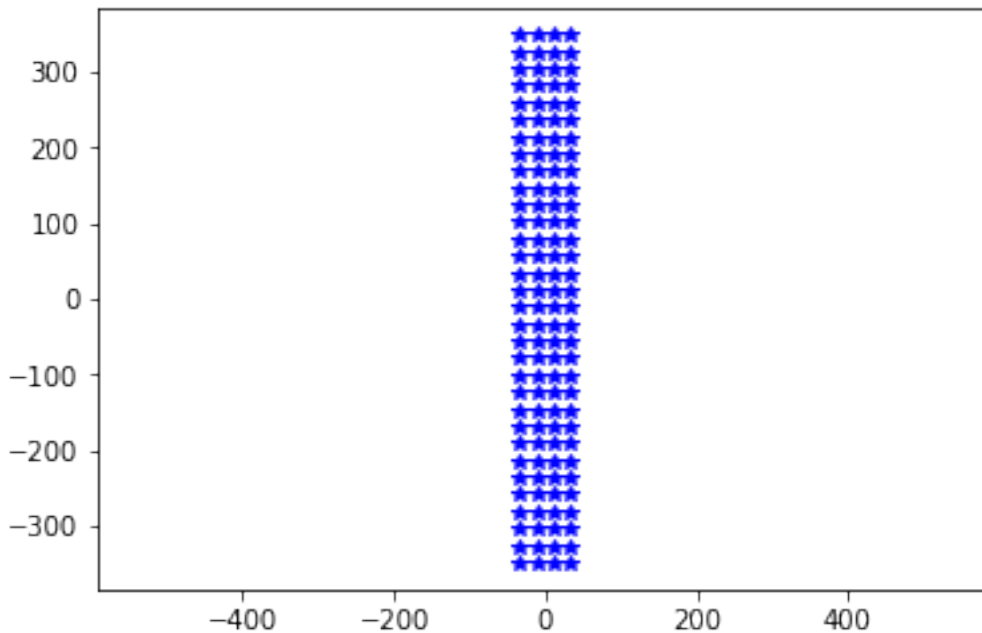
```
import MEAutility as MEA
import matplotlib.pyplot as plt
```

First, let's instantiate a MEA object among the available MEAs:

```
MEA.return_mea()
```

```
Available MEA:
['SqMEA-6-25um', 'SqMEA-10-15um', 'circle_500', 'tetrode', 'Neuroseeker-128', 'SqMEA-
↳ 5-30um', 'SqMEA-15-10um', 'Neuronexus-32-Kampff', 'Neuronexus-32-cut-30',
↳ 'Neuropixels-128', 'Neuroseeker-128-Kampff', 'Neuropixels-24', 'SqMEA-7-20um',
↳ 'Neuronexus-32', 'Neuropixels-384']
```

```
neuroseeker = MEA.return_mea('Neuroseeker-128')
plt.plot(neuroseeker.positions[:, 1], neuroseeker.positions[:, 2], 'b*')
_ = plt.axis('equal')
```



By default the MEA is instantiated with it's center of mass at (0,0,0) and electrodes lying in the plane specified in the yaml file (by default plane is yz)

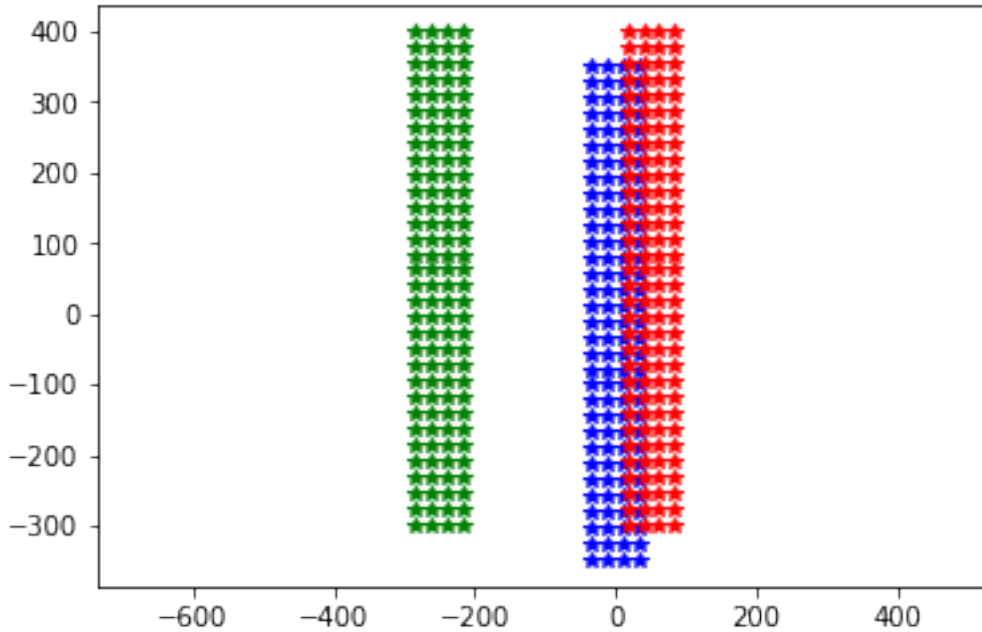
```
neuroseeker.plane
```

```
'yz'
```

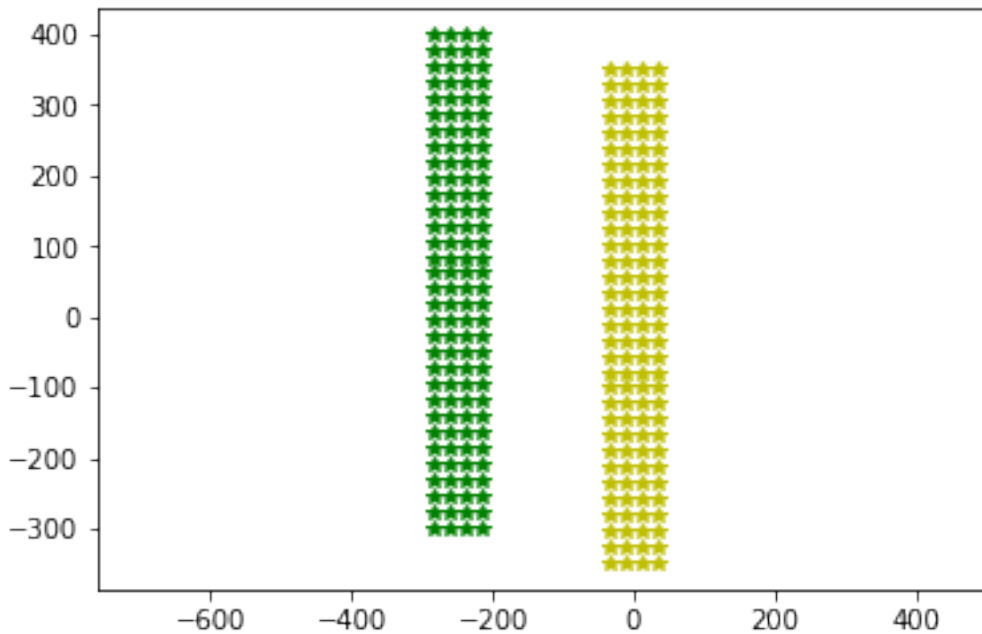
3.2.1 Moving the probe around

The probe can be easily moved with a the `move` and `center` methods:

```
plt.plot(neuroseeker.positions[:, 1], neuroseeker.positions[:, 2], 'b*')
neuroseeker.move([0, 50, 50])
plt.plot(neuroseeker.positions[:, 1], neuroseeker.positions[:, 2], 'r*')
neuroseeker.move([0, -300, 0])
plt.plot(neuroseeker.positions[:, 1], neuroseeker.positions[:, 2], 'g*')
_ = plt.axis('equal')
```



```
plt.plot(neuroseeker.positions[:, 1], neuroseeker.positions[:, 2], 'g*')
neuroseeker.center()
plt.plot(neuroseeker.positions[:, 1], neuroseeker.positions[:, 2], 'y*')
_ = plt.axis('equal')
```



3.2.2 Rotating the probe

With the `rotate` method, MEA probes can be rotated along any axis by any angle (in degrees). The current plane and orientation of the probe is stored by the variables `main_axes` and `normal`.

```
# main_axes indicate the MEA plane
print(neuroseeker.main_axes[0], neuroseeker.main_axes[1])

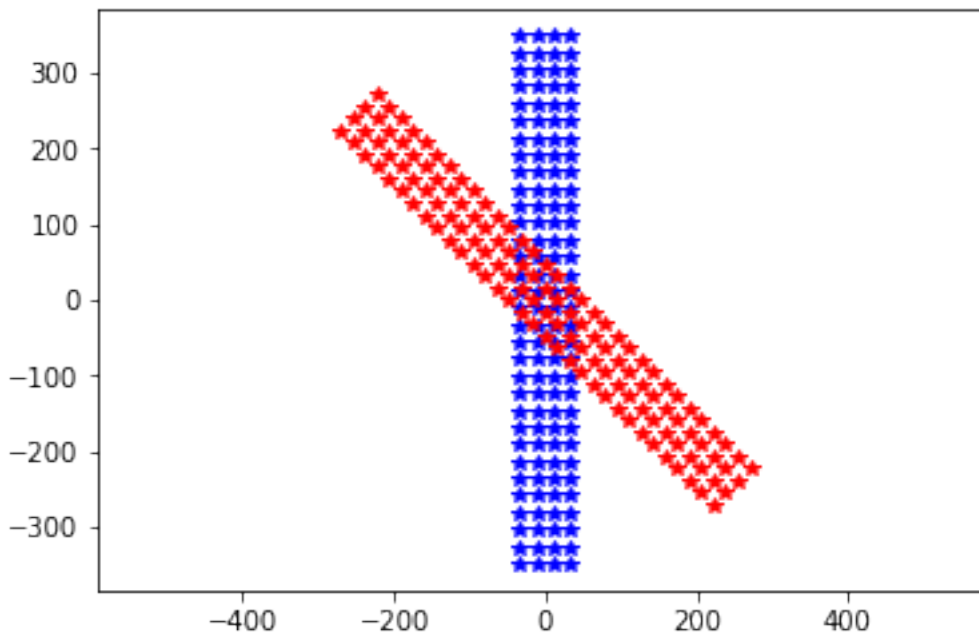
# normal indicates the axis perpendicular to the electrodes
print(neuroseeker.normal)

# normal axis is also stored by each electrode and could be changed separately
print(type(neuroseeker.electrodes[0]), neuroseeker.electrodes[0].normal)
```

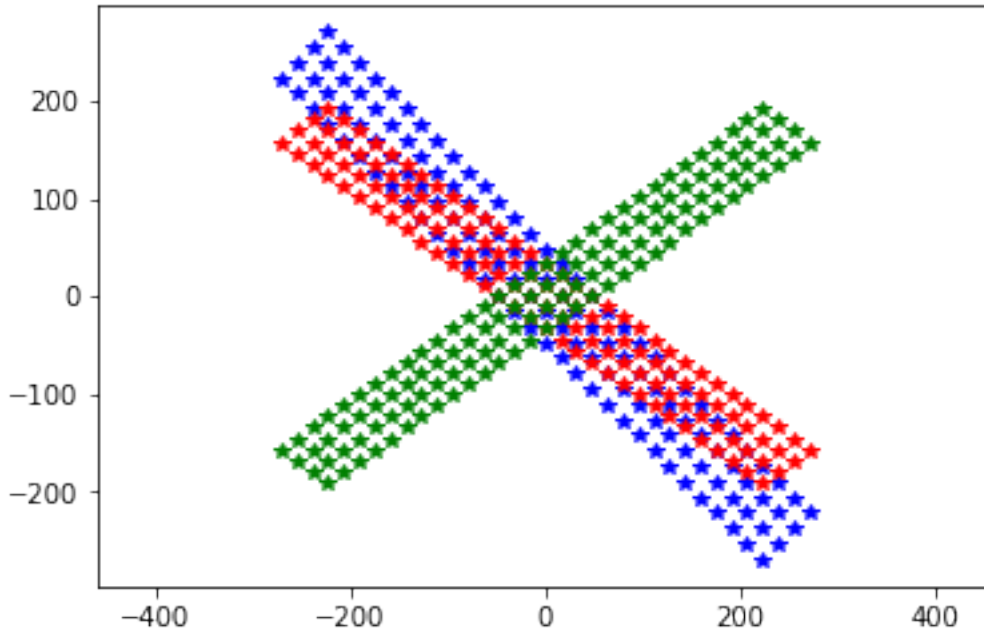
```
[0 1 0] [0 0 1]
[-1.  0.  0.]
<class 'MEAutility.core.Electrode'> [-1.  0.  0.]
```

Now let's make some rotations!!

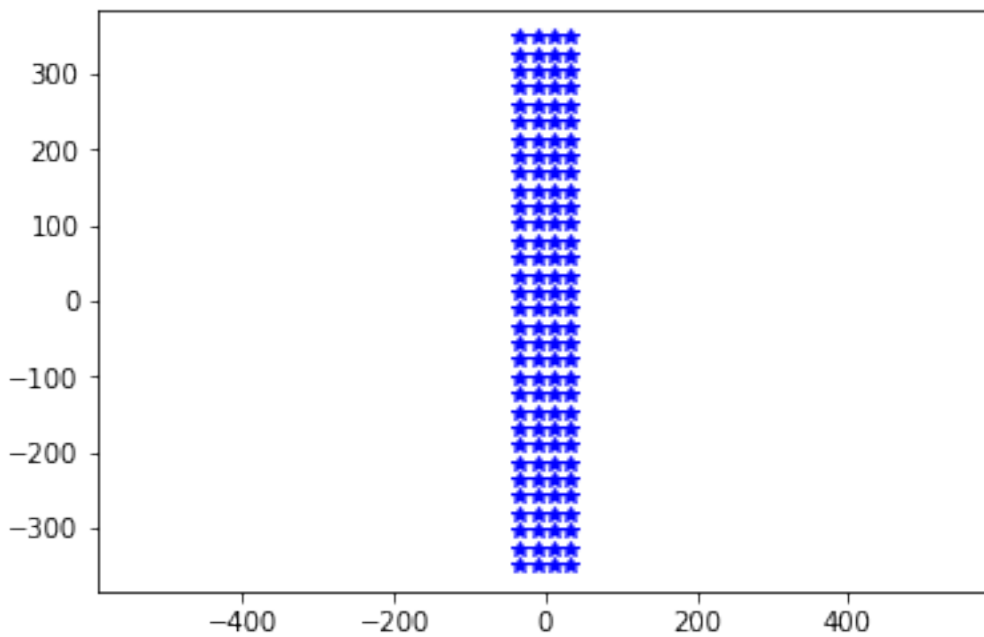
```
plt.plot(neuroseeker.positions[:, 1], neuroseeker.positions[:, 2], 'b*')
neuroseeker.rotate([1, 0, 0], 45)
plt.plot(neuroseeker.positions[:, 1], neuroseeker.positions[:, 2], 'r*')
_ = plt.axis('equal')
```



```
plt.plot(neuroseeker.positions[:, 1], neuroseeker.positions[:, 2], 'b*')
neuroseeker.rotate([0, 1, 0], 45)
plt.plot(neuroseeker.positions[:, 1], neuroseeker.positions[:, 2], 'r*')
neuroseeker.rotate([0, 1, 0], 90)
plt.plot(neuroseeker.positions[:, 1], neuroseeker.positions[:, 2], 'g*')
_ = plt.axis('equal')
```



```
# back to normal
neuroseeker.rotate([0, 1, 0], -90)
neuroseeker.rotate([0, 1, 0], -45)
neuroseeker.rotate([1, 0, 0], -45)
plt.plot(neuroseeker.positions[:, 1], neuroseeker.positions[:, 2], 'b*')
_ = plt.axis('equal')
```



3.3 MEA stimulation

This notebook shows how to simulate the electric potential generated by electrode currents using a MEA object. Stimulation is performed by means of currents. Voltage stimulation is not implemented as it strongly depends on the electrode itself (e.g. faradaic/capacitive).

```
import MEAutility as MEA
import matplotlib.pyplot as plt
import numpy as np
```

First, let's instantiate a MEA object among the available MEA models:

```
MEA.return_mea()
```

Available MEA:

```
['SqMEA-15-10um', 'SqMEA-6-25um', 'Neuronexus-32-cut-30', 'SqMEA-5-30um',
→ 'Neuropixels-384', 'SqMEA-10-15um', 'Neuropixels-128', 'SqMEA-7-20um', 'Neuronexus-
→ 32-Kampff', 'Neuroseeker-128', 'tetrode', 'Neuropixels-24', 'Neuronexus-32',
→ 'Neuroseeker-128-Kampff', 'tetrode_mea']
```

```
sqmea = MEA.return_mea('SqMEA-10-15um')
```

By default, the stimulation model is set to `semi`. This is the default for MEA objects of type `mea` and it models that currents radiate only on one side of the probe (the MEA is considered as an infinite insulating plane). The underlying assumption is that ground is infinitely far away. In this case the electric potential at point $\vec{r}$ generated by the electrode currents I_i is (electrode positions are $\vec{r}_i$):

$$V(\vec{r}) = \sum_i \frac{I_i}{2\sigma\pi|\vec{r} - \vec{r}_i|}$$

where σ is the tissue conductivity.

Instead, for `mea` type `wire`, the tissue is assumed to be infinite and homogeneous, that is the probe has no effect on the electric potential and currents radiate in all directions:

$$V(\vec{r}) = \sum_i \frac{I_i}{4\sigma\pi|\vec{r} - \vec{r}_i|}$$

3.3.1 Conventions

- currents are in nA
- distances and positions are in μm
- electric potentials are in mV

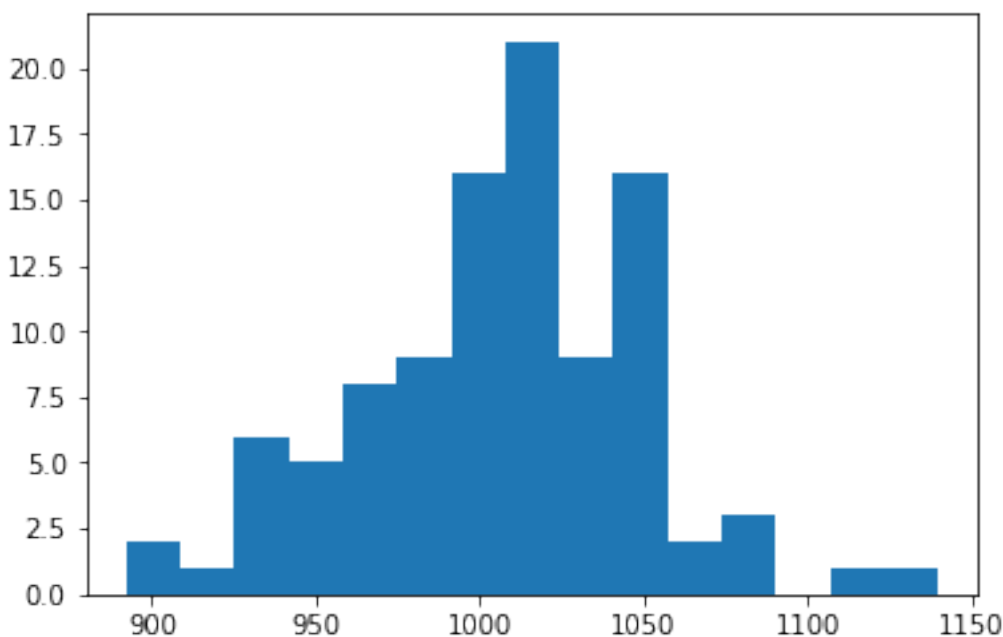
3.3.2 Handling currents

MEA currents can be easily accessed and changed in various ways:

```
# check currents
print(sqmea.currents)
```



```
[ 973.91615691 1016.83720943 1089.49043841 1139.8579249 927.79316233
1000.89661725 1047.3334144 1051.8497402 927.37268018 996.62983039
1016.49251336 1043.75742297 1004.9168758 940.30748105 1054.53993841
973.75422086 983.60405175 1042.34697708 1040.74580548 1014.98436691
1001.8608754 995.65886874 1012.95710254 970.06809296 927.99036328
999.92788465 1049.19541344 997.14646988 1039.79123706 984.20047048
930.55017661 1009.74184644 1023.24453635 1018.02056444 1049.41097968
1017.43562542 1062.60398159 973.51622737 1053.37464287 892.22969949
999.73394752 1012.93137879 980.73150404 953.77253661 951.55426365
905.11921863 1107.92750924 913.69396055 1077.18729127 962.6261477
1043.49287399 952.72622053 993.51633173 1029.79201114 1014.65998008
986.78997864 1007.9228314 973.1521672 1039.92862132 993.2816604
1058.30275146 951.99364936 1047.30143561 1004.77930621 1010.1738069
960.06196844 991.50504623 999.62108637 1037.74033168 1022.7296349
1016.31311019 1020.75966681 1039.98604723 937.02190389 1050.16695834
1041.47298494 1057.30344821 1022.87078261 1026.73934869 1049.05606228
1010.57269555 1019.66052338 977.72552581 1043.29217666 988.32520744
1003.95374263 1088.5345568 981.05722135 976.19800375 1037.08286147
1026.14202785 1016.49830716 1012.46829058 1041.29563699 1010.75733243
1005.74013272 958.06708739 1007.22074273 985.12744284 969.1025596 ]
```



For Rectangular MEAs, currents can be handled with matrices:

```
print(sqmea.get_current_matrix())
print('Shape: ', sqmea.get_current_matrix().shape)
```

```
[ [ 973.91615691 1016.49251336 1001.8608754 930.55017661 999.73394752
1043.49287399 1058.30275146 1016.31311019 1010.57269555 1026.14202785]
[1016.83720943 1043.75742297 995.65886874 1009.74184644 1012.93137879
952.72622053 951.99364936 1020.75966681 1019.66052338 1016.49830716]
[1089.49043841 1004.9168758 1012.95710254 1023.24453635 980.73150404
993.51633173 1047.30143561 1039.98604723 977.72552581 1012.46829058]
[1139.8579249 940.30748105 970.06809296 1018.02056444 953.77253661
```

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```

1029.79201114 1004.77930621 937.02190389 1043.29217666 1041.29563699]
[ 927.79316233 1054.53993841 927.99036328 1049.41097968 951.55426365
1014.65998008 1010.1738069 1050.16695834 988.32520744 1010.75733243]
[1000.89661725 973.75422086 999.92788465 1017.43562542 905.11921863
986.78997864 960.06196844 1041.47298494 1003.95374263 1005.74013272]
[1047.3334144 983.60405175 1049.19541344 1062.60398159 1107.92750924
1007.9228314 991.50504623 1057.30344821 1088.5345568 958.06708739]
[1051.8497402 1042.34697708 997.14646988 973.51622737 913.69396055
973.1521672 999.62108637 1022.87078261 981.05722135 1007.22074273]
[ 927.37268018 1040.74580548 1039.79123706 1053.37464287 1077.18729127
1039.92862132 1037.74033168 1026.73934869 976.19800375 985.12744284]
[ 996.62983039 1014.98436691 984.20047048 892.22969949 962.6261477
993.2816604 1022.7296349 1049.05606228 1037.08286147 969.1025596 ]]
Shape: (10, 10)

```

```

current_of_zeros = np.zeros((10,10))
print(current_of_zeros)

```

```

[[0. 0. 0. 0. 0. 0. 0. 0. 0. 0.]
 [0. 0. 0. 0. 0. 0. 0. 0. 0. 0.]
 [0. 0. 0. 0. 0. 0. 0. 0. 0. 0.]
 [0. 0. 0. 0. 0. 0. 0. 0. 0. 0.]
 [0. 0. 0. 0. 0. 0. 0. 0. 0. 0.]
 [0. 0. 0. 0. 0. 0. 0. 0. 0. 0.]
 [0. 0. 0. 0. 0. 0. 0. 0. 0. 0.]
 [0. 0. 0. 0. 0. 0. 0. 0. 0. 0.]
 [0. 0. 0. 0. 0. 0. 0. 0. 0. 0.]
 [0. 0. 0. 0. 0. 0. 0. 0. 0. 0.]]

```

```

sqmea.set_current_matrix(current_of_zeros)
sqmea.get_current_matrix()

```

```

array([[0., 0., 0., 0., 0., 0., 0., 0., 0., 0.],
       [0., 0., 0., 0., 0., 0., 0., 0., 0., 0.],
       [0., 0., 0., 0., 0., 0., 0., 0., 0., 0.],
       [0., 0., 0., 0., 0., 0., 0., 0., 0., 0.],
       [0., 0., 0., 0., 0., 0., 0., 0., 0., 0.],
       [0., 0., 0., 0., 0., 0., 0., 0., 0., 0.],
       [0., 0., 0., 0., 0., 0., 0., 0., 0., 0.],
       [0., 0., 0., 0., 0., 0., 0., 0., 0., 0.],
       [0., 0., 0., 0., 0., 0., 0., 0., 0., 0.],
       [0., 0., 0., 0., 0., 0., 0., 0., 0., 0.]])

```

Single currents can be set separately either by:

```

# set electrode 50 current to 10000
sqmea.set_current(24, 10000)
sqmea.currents

```

```

array([[ 0.,  0.,  0.,  0.,  0.,  0.,  0.,  0.,
         0.,  0.,  0.,  0.,  0.,  0.,  0.,  0.,
        10000.,  0.,  0.,  0.,  0.,  0.,  0.,  0.,
         0.,  0.,  0.,  0.,  0.,  0.,  0.,  0.,
         0.,  0.,  0.,  0.,  0.,  0.,  0.,  0.]])

```

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```

0., 0., 0., 0., 0., 0., 0., 0.,
0., 0., 0., 0., 0., 0., 0., 0.,
0., 0., 0., 0., 0., 0., 0., 0.,
0., 0., 0., 0., 0., 0., 0., 0.,
0., 0., 0., 0., 0., 0., 0., 0.,
0., 0., 0., 0., 0., 0., 0., 0.,
0., 0., 0., 0., 0., 0., 0., 0.,
0., 0., 0., 0., 0., 0., 0., 0.]

```

Or by using matrix notation for rectangular MEAs. This makes it easy, for example, to create multipolar current sets.

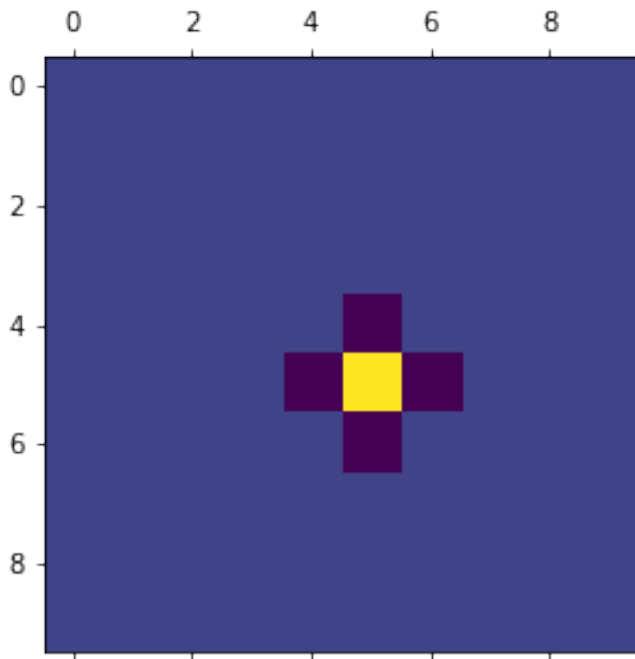
```

# reset electrode 50 current to 0
sqmea.set_current(24, 0)
center_electrode = sqmea.dim[0]//2

# build a multipolar current set
sqmea[center_electrode][center_electrode].current = 8000
sqmea[center_electrode+1][center_electrode].current = -2000
sqmea[center_electrode-1][center_electrode].current = -2000
sqmea[center_electrode][center_electrode+1].current = -2000
sqmea[center_electrode][center_electrode-1].current = -2000

_ = plt.matshow(sqmea.get_current_matrix())

```



3.3.3 Stimulation

Once currents are set, electric potentials can be computed with the `compute_field` function. Let's first create a bunch of 3d points, for example, on a straight line from close to the active electrode.

```

center_pos = sqmea[center_electrode][center_electrode].position
print(center_pos)

```

```
[0.  7.5 7.5]
```

```
npoints = 1000
x_vec = np.linspace(5, 100, npoints)
y_vec = [center_pos[1]] * npoints
z_vec = [center_pos[2]] * npoints

points = np.array([x_vec, y_vec, z_vec]).T
# points should be a np.array (or list) o npoints x 3
print(points.shape)
print(points)
```

```
(1000, 3)
[[  5.          7.5          7.5          ]
 [ 5.0950951    7.5          7.5          ]
 [ 5.19019019    7.5          7.5          ]
 ...
 [ 99.80980981   7.5          7.5          ]
 [ 99.9049049    7.5          7.5          ]
 [100.          7.5          7.5          ]]
```

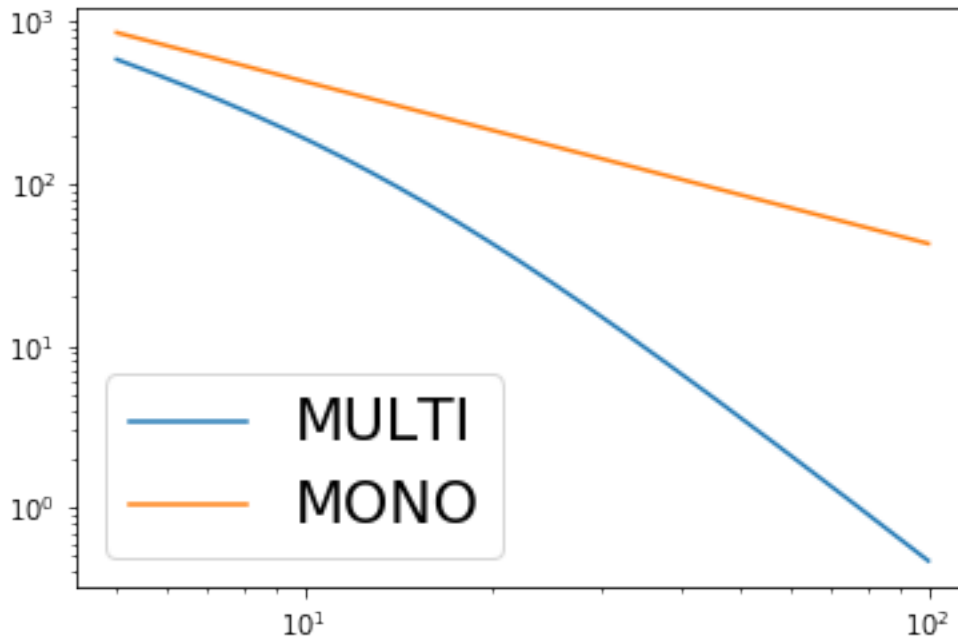
Now, we can compute the electric potential:

```
# multipolar currents
Vp_multi = sqmea.compute_field(points)
```

and compare the field generated by a single electrode (monopolar current source).

```
# monopolar currents
sqmea.reset_currents()
sqmea[5][5].current = 8000
Vp_mono = sqmea.compute_field(points)
```

```
_ = plt.loglog(x_vec, Vp_multi, label='MULTI')
_ = plt.loglog(x_vec, Vp_mono, label='MONO')
_ = plt.legend(fontsize=22)
```



The potential fall for the multipolar is faster than the monopolar configuration (which is linear in log scale)!

3.3.4 Finite electrode effect

So far, we assumed that the electrodes were point sources, but this is of course not the case as they have a finite size. In some cases the finite size of the electrode may be taken into consideration. In order to do so, one can set the variable `points_per_electrode` of the MEA object to the number of points within the electrode in which the entire electrode current is split.

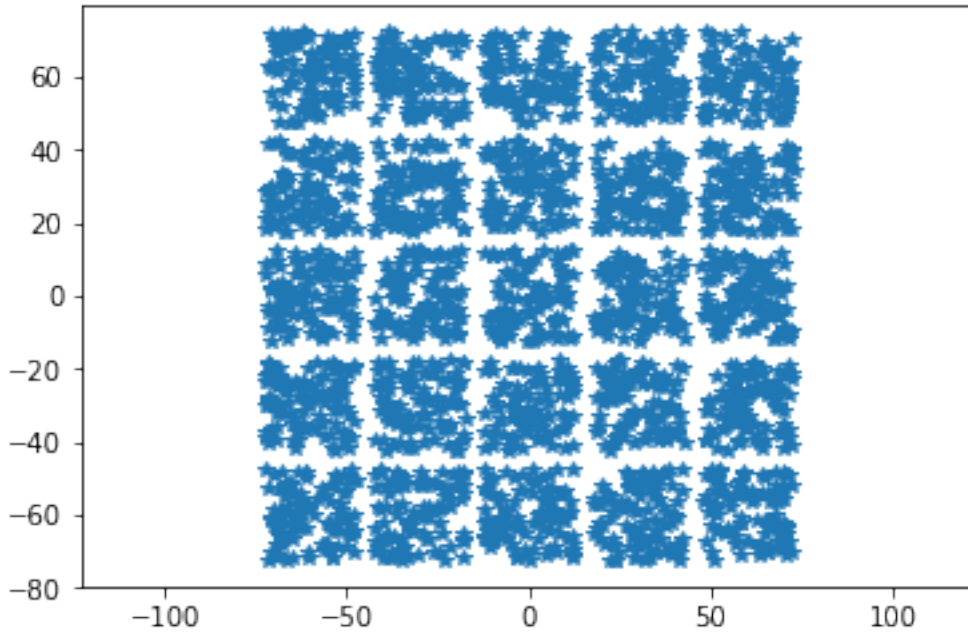
Let's take a look at an example:

```
sqmea_r = MEA.return_mea('SqMEA-5-30um')
center_electrode = sqmea_r.dim[0] // 2

# Activate all electrodes
sqmea_r.set_random_currents(mean=0, sd=10000)
reduced_points = points[:10]
```

```
sqmea_r.points_per_electrode = 100

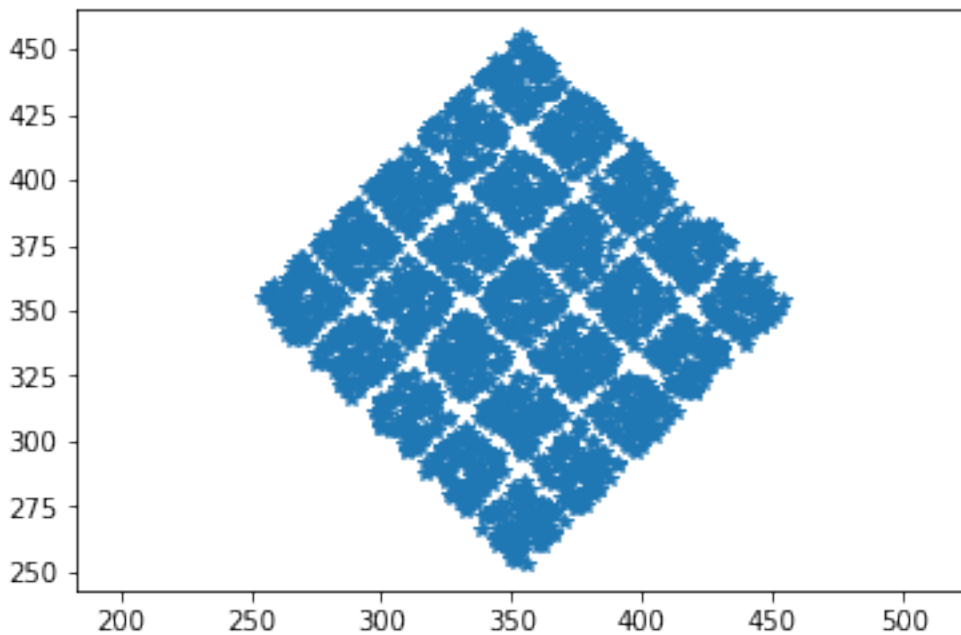
# compute electric potential and return stimulation points
vp, stim_points = sqmea_r.compute_field(reduced_points, return_stim_points=True)
_ = plt.plot(stim_points[:, 1], stim_points[:, 2], '*')
_ = plt.axis('equal')
```



The stimulation points are within the electrode square. Stimulation positions are consistent with after probe shifts and rotations:

```
sqmea_r.move([0,500,0])
sqmea_r.rotate([1, 0, 0], 45)

# compute electric potential and return stimulation points
vp, stim_points = sqmea_r.compute_field(reduced_points, return_stim_points=True)
_ = plt.plot(stim_points[:, 1], stim_points[:, 2], '*')
_ = plt.axis('equal')
```



The effect of the electrode finite size on the electric potential in proximity of the stimulation site is shown in the `MEA_plotting` section.

3.3.5 Temporal dynamics

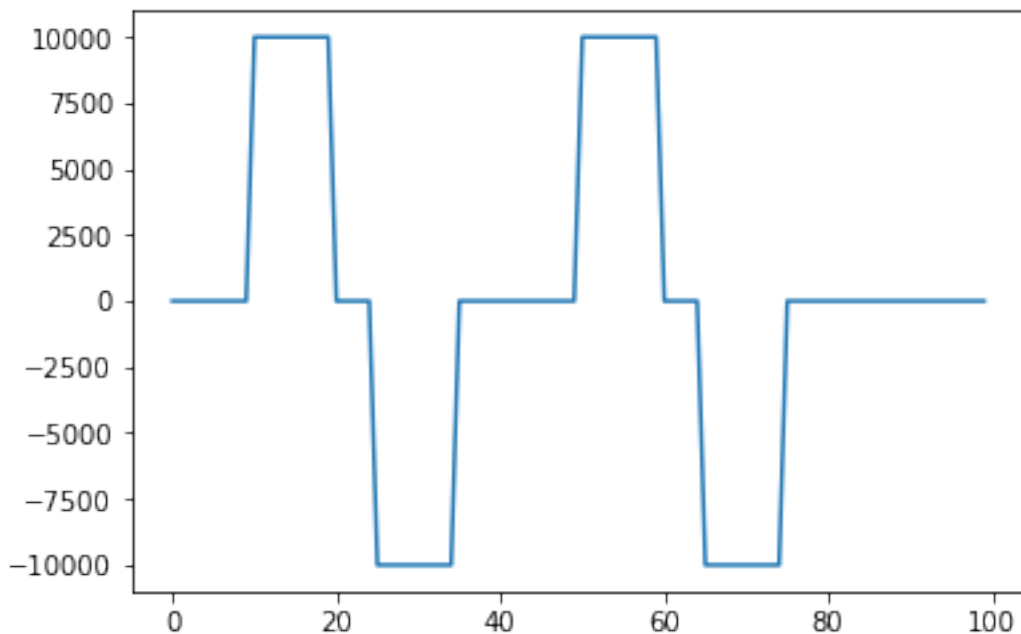
So far, we used *static* currents, but the effect of current dynamics can be very important for exciting neurons. Temporal varying currents can be easily implemented with the MEAutility package.

Let's instantiate a new MEA object and set a monopolar biphasic source with 2 pulses:

```
sqmea = MEA.return_mea('SqMEA-10-15um')
center_electrode = sqmea.dim[0] // 2

ntimes = 100
bipolar_source = np.zeros(ntimes)
bipolar_source[10:20] = 10000
bipolar_source[25:35] = -10000
bipolar_source[50:60] = 10000
bipolar_source[65:75] = -10000

_ = plt.plot(bipolar_source)
```

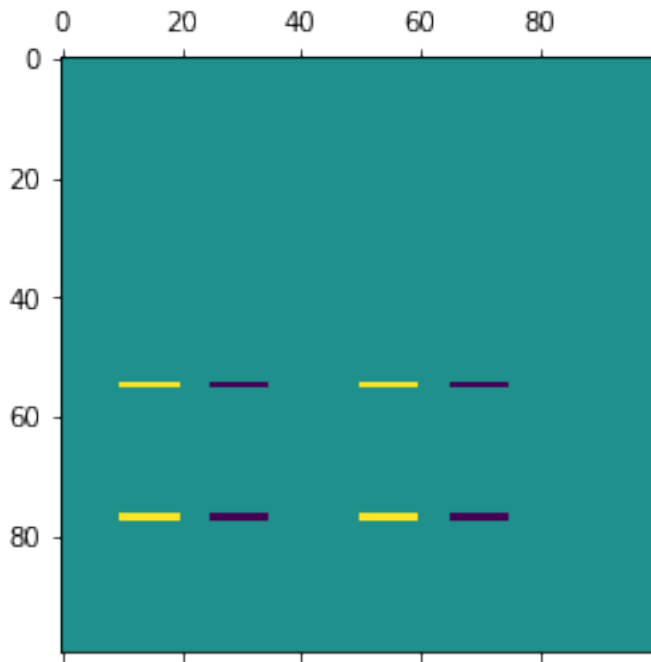


```
# the current can be set directly accessing the electrode current
sqmea[center_electrode][center_electrode].current = bipolar_source

# OR

# using set_current() (get_linear_id returns the index of the matrix in the linear_
↪array)
sqmea.set_current(sqmea.get_linear_id(center_electrode+2, center_electrode+2),
↪bipolar_source)
```

```
_ = plt.matshow(sqmea.currents)
```

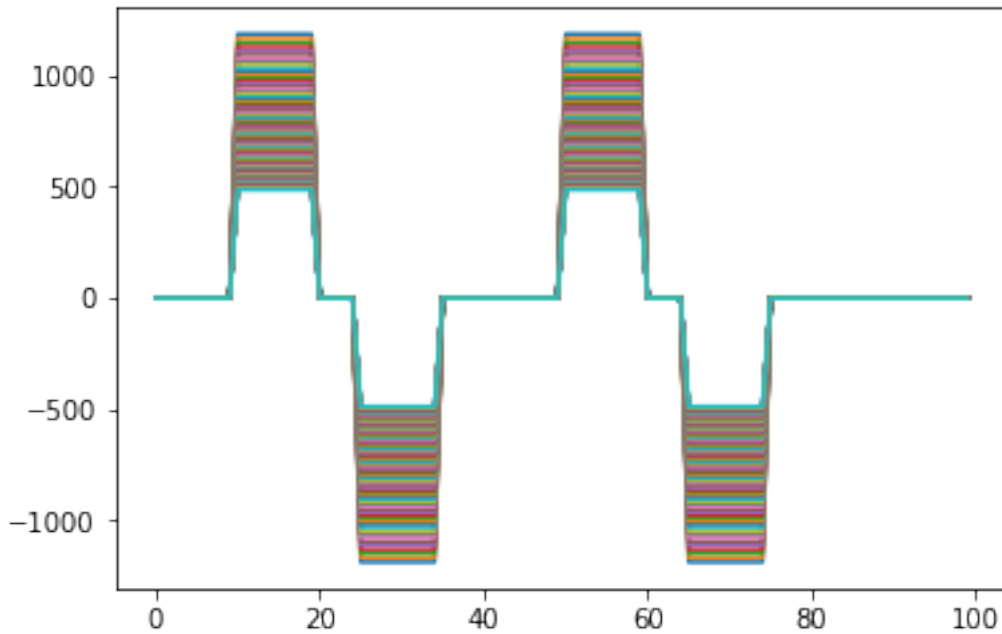


Computing the electrical potential returns an array when currents have temporal dynamics:

```
vp = sqmea.compute_field(points[:100])
```

```
print(vp.shape)  
_ = plt.plot(vp.T)
```

```
(100, 100)
```



As expected the potential becomes lower moving further away from the probe!

3.4 MEA plotting

This notebook shows some plotting routines implemented in the MEAutility package.

```
import MEAutility as MEA
import matplotlib.pyplot as plt
import numpy as np
%matplotlib notebook
```

3.4.1 2D plotting

As usual, let's first define some MEA objects:

```
sqmea = MEA.return_mea('SqMEA-10-15um')
neuronexus = MEA.return_mea('Neuronexus-32')
neuropixels = MEA.return_mea('Neuropixels-128')
```

The `plot_probe()` function plots the probe in 2D. The axis is returned and an existing axis can be passed with the `ax` argument. Here are some examples:

```
MEA.plot_probe(neuropixels)
```

```
<matplotlib.axes._subplots.AxesSubplot at 0x7f4d5a79f630>
```

```
fig, ax1 = plt.subplots()
ax1 = MEA.plot_probe(neuronexus, ax=ax1, type='shank')
_ = ax1.axis('off')
```

`plot_probe()` always plots the probe along its main axes:

```
neuronexus.rotate([1,0,0], 45)
ax1 = MEA.plot_probe(neuronexus, type='shank')
_ = ax1.axis('off')
```

```
_ = MEA.plot_probe(sqmea, type='planar', xlim=[-400,400], ylim=[-200,200])
```

To visualize the stimulating currents, one can use the `color_currents` parameter:

```
sqmea.set_random_currents()
ax = MEA.plot_probe(sqmea, color_currents=True)
```

```
# colormap can be changed
ax = MEA.plot_probe(sqmea, color_currents=True, cmap='hot')
```

3.4.2 3D plotting

The function `plot_probe_3d` allows to plot MEA objects in 3d axes. The plots reflect the current position and rotation of the MEA.

```
neuronexus = MEA.return_mea('Neuronexus-32')
_ = MEA.plot_probe_3d(neuronexus)
```

```
neuronexus.rotate([1,0,0], 45)
_ = MEA.plot_probe_3d(neuronexus)
```

```
neuronexus.set_random_currents()
_ = MEA.plot_probe_3d(neuronexus, color_currents=True, cmap='jet')
```

```
ax = MEA.plot_probe_3d(neuronexus, color_currents=True, cmap='jet',
                       xlim=[-100,100], ylim=[-100,100], zlim=[-100,100])
_ = ax.axis('off')
```

3.4.3 Electric potential images

The functions `plot_v_image()` and `plot_v_surf()` allows the user to plot potential images on a plane. The plane can be defined with the `plane` argument and boundaries can be given with `x_bound`, `y_bound`, and `z_bound` arguments (e.g. if plane is `xz`, `x_bound` and `z_bound` are required). The offset on the other direction (i.e. `y` when plane is `xz`) is controlled by the `offset` parameter.

```
sqmea = MEA.return_mea('SqMEA-10-15um')
sqmea.points_per_electrode = 1
sqmea.reset_currents()
sqmea[0][0].current = 10000
sqmea[5][0].current = 10000
sqmea[0][7].current = 10000
```

```
_ = MEA.plot_v_image(sqmea, y_bound=[-100, 100], z_bound=[-100, 100], plane='yz',
                    ↪offset=10)
```

With `plot_v_image` we can show the effect of electrodes of finite sizes:

```
print(sqmea[0][0].position)
```

```
[ 0. -67.5 -67.5]
```

```
fig, axes = plt.subplots(1, 2)
# points per electrode = 1
sqmea.points_per_electrode = 1
_, v1 = MEA.plot_v_image(sqmea, y_bound=[-55, -80], z_bound=[-55, -80], offset=2,
                        npoints=30, plane='yz', ax=axes[0])

# points per electrode = 100
sqmea.points_per_electrode = 100
_, v100 = MEA.plot_v_image(sqmea, y_bound=[-55, -80], z_bound=[-55, -80], offset=2,
                          npoints=30, plane='yz', ax=axes[1])
```

The finite size results in a *squarer* electric potential in proximity of the electrode!

```
fig = plt.figure()
ax1 = fig.add_subplot(1, 2, 1, projection='3d')
ax2 = fig.add_subplot(1, 2, 2, projection='3d')

sqmea.points_per_electrode = 1
_ = MEA.plot_v_surf(sqmea, v_plane=v1, y_bound=[-55, -80], z_bound=[-55, -80],
    ↪offset=10,
                        npoints=30, plane='yz', ax=ax1)

_ = MEA.plot_v_surf(sqmea, v_plane=v100, y_bound=[-55, -80], z_bound=[-55, -80],
    ↪offset=10,
                        npoints=30, plane='yz', ax=ax2)
```

```
sqmea.points_per_electrode = 1
sqmea[0][0].current = 10000
ax, v = MEA.plot_v_surf(sqmea, y_bound=[-100, 100], z_bound=[-100, 100],
                        plane='yz', plot_plane='yz', offset=30, distance=200)
MEA.plot_probe_3d(sqmea, ax=ax, xlim=[-500, 500], color_currents=True)
```

```
<matplotlib.axes._subplots.Axes3DSubplot at 0x7f4d5829be48>
```

```
sqmea.rotate([0,1,0], 90)
print(sqmea.main_axes)
```

```
[[0. 1. 0.]
 [1. 0. 0.]]
```

```
ax, v = MEA.plot_v_surf(sqmea, x_bound=[-100, 100], y_bound=[-100, 100],
                        plane='xy', plot_plane='xy', offset=30, distance=30)
MEA.plot_probe_3d(sqmea, ax=ax, xlim=[-100, 100], zlim=[-100, 300], color_
    ↪currents=True, type='planar')
```

```
<matplotlib.axes._subplots.Axes3DSubplot at 0x7f4d4aed14e0>
```

```
sqmea.rotate([0,1,0], -90)
sqmea.rotate([0,0,1], -90)
print(sqmea.main_axes)
```

```
[[1. 0. 0.]
 [0. 0. 1.]]
```

```
ax, v = MEA.plot_v_surf(sqmea, x_bound=[-100, 100], z_bound=[-100, 100],
                        plane='xz', plot_plane='xz', offset=30, distance=100)
MEA.plot_probe_3d(sqmea, ax=ax, color_currents=True,)
```

```
<matplotlib.axes._subplots.Axes3DSubplot at 0x7f4d582e0710>
```

3.4.4 Plot signal traces

```
# fake noise signal
signals = np.random.randn(sqmea.number_electrodes, 10000)
_ = MEA.plot_mea_recording(signals, sqmea, lw=0.1)
```

3.4.5 Animations

```
# %matplotlib notebook
# from IPython.display import HTML

# anim = MEA.play_mea_recording(signals, sqmea, 1000, interval =100, lw=0.1)
# HTML(anim.to_jshtml())
```

3.5 Module MEAutility.core

3.6 Module MEAutility.plotting

CHAPTER 4

Contact

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