1. Generate synthetic dataset

In [1]:
```
import numpy as np
from scipy.integrate import odeint
import quantities as pq
import neo
from elephant.spike_train_generation import inhomogeneous_poisson_process
```

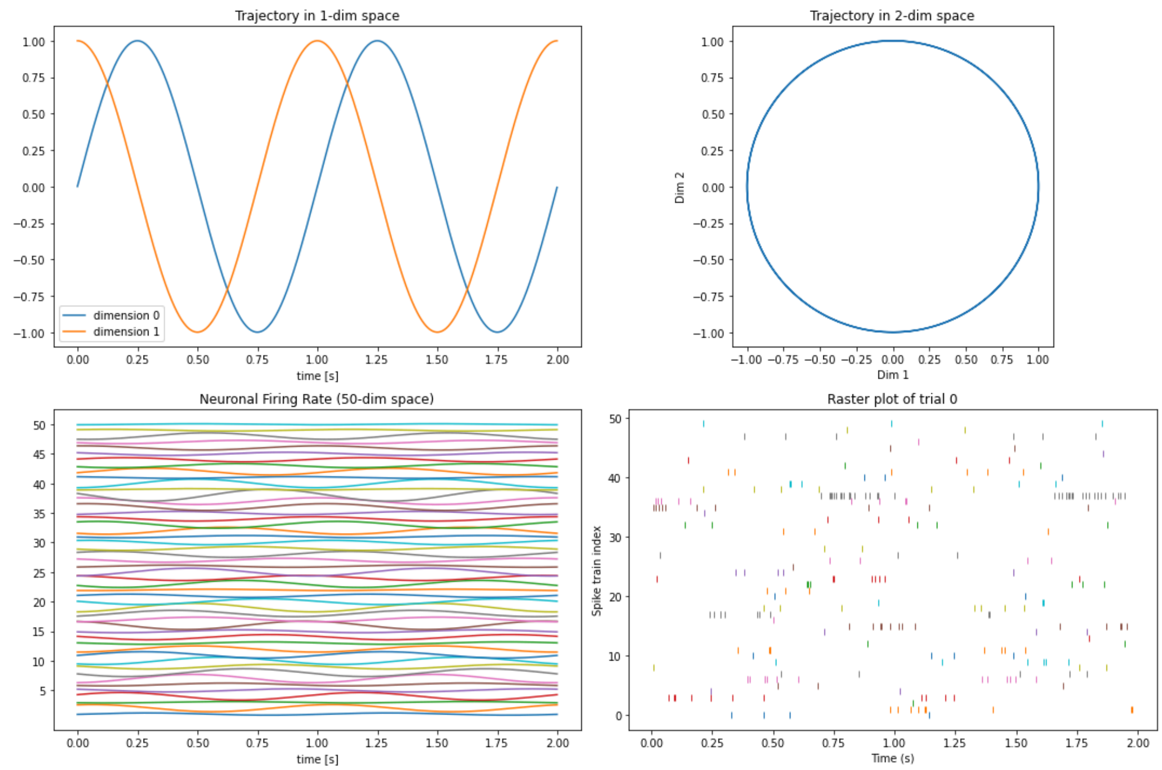
In [2]:
```
from elephant.gpfa import GPFA
```

The following code is taken from this [tutorial (https://elephant.readthedocs.io/en/latest/tutorials/gpfa.html)](https://elephant.readthedocs.io/en/latest/tutorials/gpfa.html) as validation of our implementation.

In [3]:
```
def integrated_oscillator(dt, num_steps, x0=0, y0=1, angular_frequency=2*np.pi*1e-3):
    """
    Parameters
    ----------
    dt : float
        Integration time step in ms.
    num_steps : int
        Number of integration steps -> max_time = dt*(num_steps-1).
    x0, y0 : float
        Initial values in three dimensional space.
    angular_frequency : float
        Angular frequency in 1/ms.

    Returns
    -------
    t : (num_steps) np.ndarray
        Array of timepoints
    (2, num_steps) np.ndarray
        Integrated two-dimensional trajectory (x, y, z) of the harmonic oscillator
    """

    assert isinstance(num_steps, int), "num_steps has to be integer"
    t = dt*np.arange(num_steps)
    x = x0*np.cos(angular_frequency*t) + y0*np.sin(angular_frequency*t)
    y = -x0*np.sin(angular_frequency*t) + y0*np.cos(angular_frequency*t)
    return t, np.array((x, y))


def random_projection(data, embedding_dimension, loc=0, scale=None):
    """
    Parameters
    ----------
    data : np.ndarray
        Data to embed, shape=(M, N)
    embedding_dimension : int
        Embedding dimension, dimensionality of the space to project to.
    loc : float or array_like of floats
        Mean (“centre”) of the distribution.
    scale : float or array_like of floats
        Standard deviation (spread or “width”) of the distribution.

    Returns
    -------
    np.ndarray
       Random (normal) projection of input data, shape=(dim, N)

    See Also
    --------
    np.random.normal()

    """
    if scale is None:
        scale = 1 / np.sqrt(data.shape[0])
    projection_matrix = np.random.normal(loc, scale, (embedding_dimension, data.shape[0]))
    return np.dot(projection_matrix, data)


def generate_spiketrains(instantaneous_rates, num_trials, timestep):
    """
    Parameters
    ----------
    instantaneous_rates : np.ndarray
        Array containing time series.
    timestep :
        Sample period.
    num_steps : int
        Number of timesteps -> max_time = timestep*(num_steps-1).

    Returns
    -------
    spiketrains : list of neo.SpikeTrains
        List containing spiketrains of inhomogeneous Poisson
        processes based on given instantaneous rates.

    """

    spiketrains = []
    for _ in range(num_trials):
        spiketrains_per_trial = []
        for inst_rate in instantaneous_rates:
            anasig_inst_rate = neo.AnalogSignal(inst_rate, sampling_rate=1/timestep, units=pq.Hz)
            spiketrains_per_trial.append(inhomogeneous_poisson_process(anasig_inst_rate))
        spiketrains.append(spiketrains_per_trial)

    return spiketrains
```

In [4]:
```
# set parameters for the integration of the harmonic oscillator
timestep = 1 * pq.ms
trial_duration = 2 * pq.s
num_steps = int((trial_duration.rescale('ms')/timestep).magnitude)

# set parameters for spike train generation
max_rate = 70 * pq.Hz
np.random.seed(42)  # for visualization purposes, we want to get identical spike trains at any run

# specify data size
num_trials = 20
num_spiketrains = 50

# generate a low-dimensional trajectory
times_oscillator, oscillator_trajectory_2dim = integrated_oscillator(
    timestep.magnitude, num_steps=num_steps, x0=0, y0=1)
times_oscillator = (times_oscillator*timestep.units).rescale('s')

# random projection to high-dimensional space
oscillator_trajectory_Ndim = random_projection(
    oscillator_trajectory_2dim, embedding_dimension=num_spiketrains)

# convert to instantaneous rate for Poisson process
normed_traj = oscillator_trajectory_Ndim / oscillator_trajectory_Ndim.max()
instantaneous_rates_oscillator = np.power(max_rate.magnitude, normed_traj)

# generate spike trains
spiketrains_oscillator = generate_spiketrains(
    instantaneous_rates_oscillator, num_trials, timestep)
```

In [5]:
```
import matplotlib.pyplot as plt


f, ((ax1, ax2), (ax3, ax4)) = plt.subplots(2, 2, figsize=(15, 10))

ax1.set_title('Trajectory in 1-dim space')
ax1.set_xlabel('time [s]')
for i, y in enumerate(oscillator_trajectory_2dim):
    ax1.plot(times_oscillator, y, label=f'dimension {i}')
ax1.legend()

ax2.set_title('Trajectory in 2-dim space')
ax2.set_xlabel('Dim 1')
ax2.set_ylabel('Dim 2')
ax2.set_aspect(1)
ax2.plot(oscillator_trajectory_2dim[0], oscillator_trajectory_2dim[1])

ax3.set_title(f'Neuronal Firing Rate ({num_spiketrains}-dim space)')
ax3.set_xlabel('time [s]')
y_offset = oscillator_trajectory_Ndim.std() * 3
for i, y in enumerate(oscillator_trajectory_Ndim):
    ax3.plot(times_oscillator, y + i*y_offset)

yticks = np.arange(len(oscillator_trajectory_Ndim)) * oscillator_trajectory_Ndim.std() * 3
yticklabels = np.arange(len(oscillator_trajectory_Ndim)) + 1
ax3.set_yticks(yticks[4::5])
ax3.set_yticklabels(yticklabels[4::5])

trial_to_plot = 0
ax4.set_title(f'Raster plot of trial {trial_to_plot}')
ax4.set_xlabel('Time (s)')
ax4.set_ylabel('Spike train index')
for i, spiketrain in enumerate(spiketrains_oscillator[trial_to_plot]):
    ax4.plot(spiketrain, np.ones_like(spiketrain) * i, ls='', marker='|')

plt.tight_layout()
plt.show()
```



In [6]:
```
# bin data for GPFA
from elephant.gpfa.gpfa_util import get_seqs
```

In [7]:
```
bin_size = 20 * pq.ms
seqs = get_seqs(spiketrains_oscillator, bin_size, use_sqrt=True)
```

The final output seqs has the format

In [8]:
```
"""
seqs : np.recarray
        data structure, whose nth entry (corresponding to the nth experimental
        trial) has fields
        T : int
            number of timesteps in the trial
        y : (yDim, T) np.ndarray
            neural data
""";
```

In [9]:
```
np.save('simulated_data1.npy', seqs)
```

In [10]:
```
np.save('simulated_groundtruth.npy', oscillator_trajectory_2dim)
```

In [11]:
```
# load numpy array like this:
# arr = np.load('simulated_data1.npy',allow_pickle=True)
```

In [ ]: