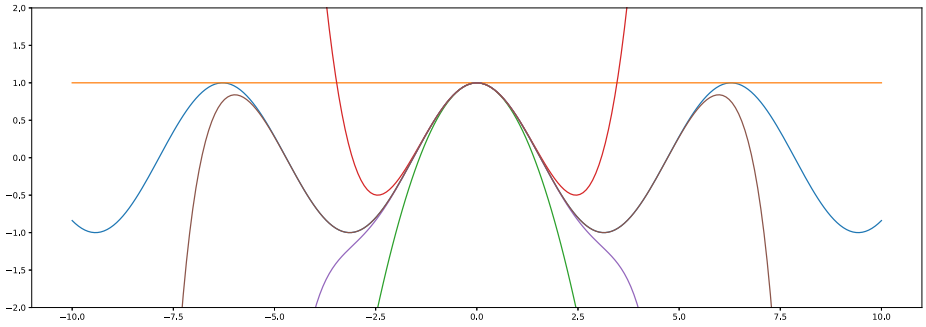
Numpy ❤ Matplotlib

Fast and elegant numeric calulations in python using numpy
and easy plotting using matplotlib



Enable native scrolling

But first:
solutions to the last homework

Guessing game

```
1  def game_iteration(bound_lower, bound_upper):
2      …
3
4      if cmd == '1':
5          return(game_iteration(bound_lower,guess)+1)
6      elif cmd == '2':
7          return(game_iteration(guess,bound_upper)+1)
8      elif cmd == '3':
9          return(1)
```

…

Fixed tic tac toe game

```
1  # Check rows
2  if self.field[0][0]==player and self.field[1][0]…
3      return True
4
5  if self.field[0][1]==player and self.field[1][1]…
6      return True
```

…

Optimized tic tac toe game

```
# Check if player owns all the fields in a row
for col in range(3):
    if all(
        self.field[row][col] == player
        for row in range(3)):

        return True
```

...

Back to numpy & matplotlib

Importing numpy and matplotlib

Open an interactive python session by running `python3` / `python` on the commandline and enter the import statements below:

```
>>> import numpy as np
>>> import matplotlib.pyplot as plt
```

The statements above tell the interpreter that we want to use the `numpy` and `matplotlib.pyplot` modules and that we want to use `np` and `plt` as a shorthand for their name

Everything is a vector

numpy is centered around a similar concept as Matlab: everything is a vector

To find out what that means we will create a vector that will be used as our x-axis

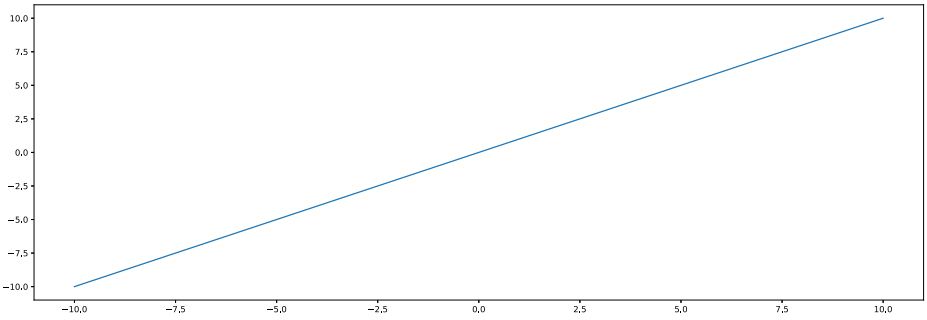
```
>>> x= np.linspace(-10, 10, 1024)
```

The statement above will create an array of 1024-elements between `-10` and `10`

```
>>> print(x)
[-10. -9.98044966 ..., 9.98044966  10.]
>>> print(len(x), x[0], x[-1])
1024 -10.0 10.0
```

Plotting

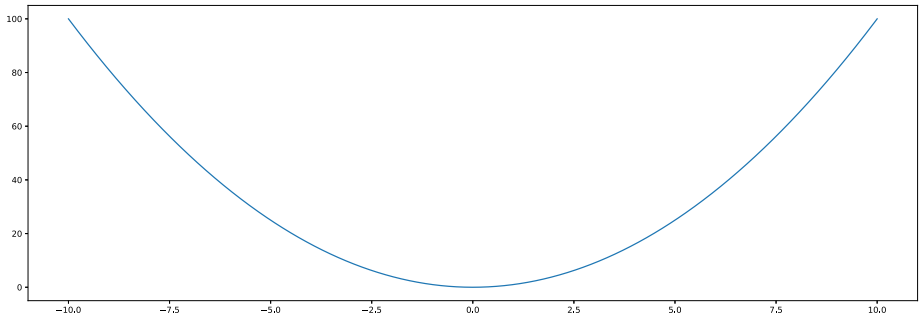
To get an idea of what `x` looks like we can plot it over itself




```
>>> plt.plot(x, x) # Plot x over x
>>> plt.show()     # Show the plot in a window
```


Everything is a vector

Numpy lets us work with vectors as if they were numbers




```
>>> plt.plot(x, x**2) # Plot x² over x
>>> plt.show()
```

`x**2` calculates x^2 for every element of x

Working with vectors

The "everything is a vector" concept lets us express complex problems with little code

```
>>> y= x**2
>>> dy= y[1:] - y[:-1]
>>> dx= x[1:] - x[:-1]
>>> plt.plot(x[1:], dy/dx)
>>> plt.show()
```

What is the purpose of the snippet above?

Choose your track

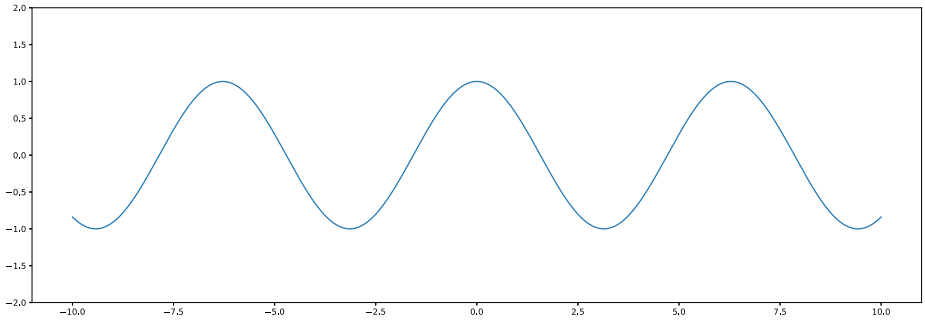
Based on your programming experience you can now decide how you want to continue this tutorial:

- Green track - a simple example demonstrating the taylor-expansion
- Red track - a more complex example that performs basic digital signal processing on an actual radio signal

To learn how to use numpy and matplotlib you should follow the green track

Green track

The taylor expansion is a method to approximate some function using polynomials



We want to plot the taylor expansion of a cosine

Download the skeleton code that plots a cosine and run it

Taylor expansion

Look up the taylor expansion of a cosine on wikipedia

and continue the expansion started in the skeleton code

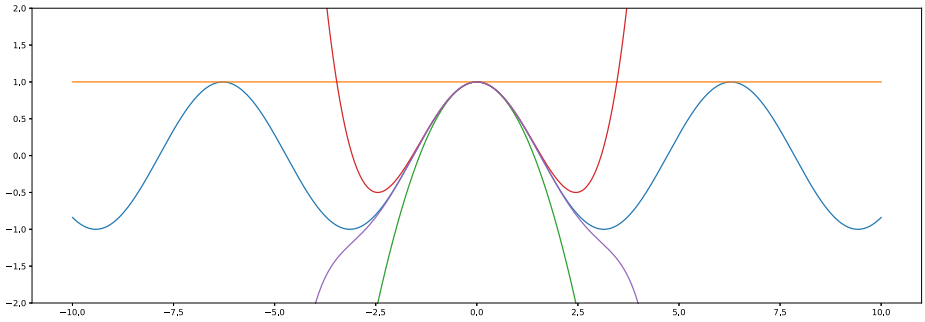
```
f_t1= 1 * x**0
f_t2= f_t1 - 1/2 * x**2
f_t3= 0 # TODO
f_t4= 0 # TODO
```


Multiple plots

In order to plot multiple plots into the same window you can pass multiple x/y-data pairs to the `.plot` function

```
plt.plot(
    x, f_cos,
    x, f_t1,
    x, f_t2,
    x, f_t3,
    x, f_t4
)
```

Solution



```
f_t1= 1 * x**0
f_t2= f_t1 - 1/2 * x**2
f_t3= f_t2 + 1/24 * x**4
f_t4= f_t3 - 1/720 * x**6
```

...

Higher order

Manual expansion becomes tedious for higher orders

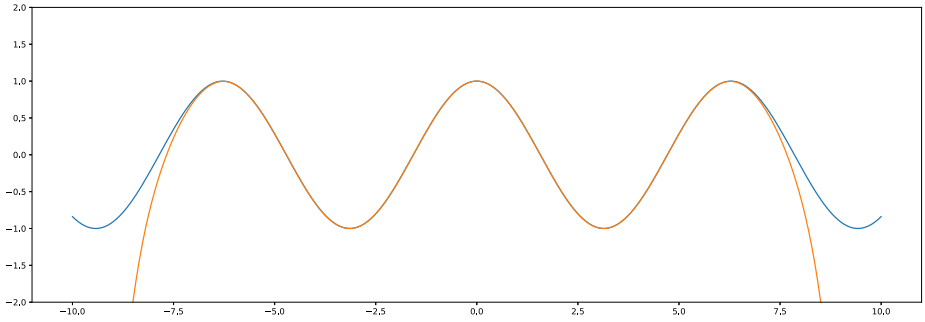
Download the skeleton code below and implement the cosine taylor expansion using a for-loop

```
for n in range(10):
    f_taylor+= x # TODO
```

...

Hint: use the `math.factorial` function

Solution

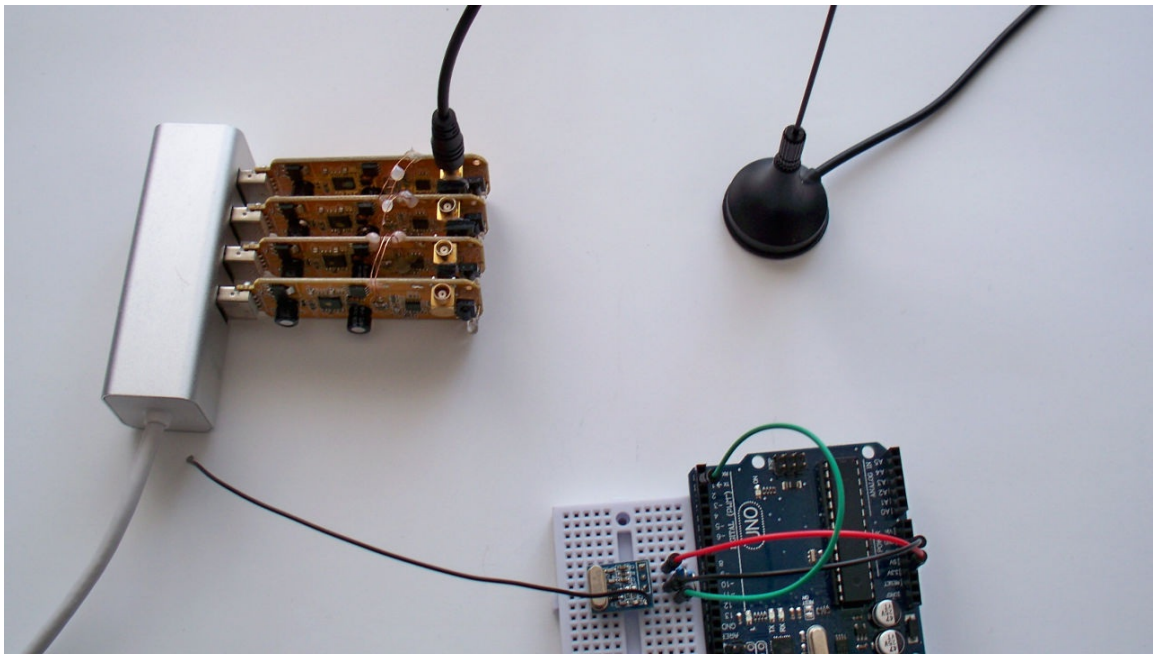


```
for n in range(10):
    f_taylor+= (
        ((-1)**n)/math.factorial(2*n) * x**(2*n)
    )
```

...

Red track

The setup that generated the testdata consists of an Arduino, a 433MHz OOK RF-module and a DVB-T stick that is abused to work as a software defined radio



The Arduino generates data that is transmitted by the RF-module

The SDR reveices the signal, does some processing and passes the digitized signal to the PC

uart.bin

The SDR outputs two 8-bit unsigned values per sample, the real and the imaginary part of a complex number

The SDR was configured to record samples at a rate of 960kHz, meaning one sample every 1.04µs

The SDR was also configured to work at a center-frequency of 433.8MHz, meaning that a signal at 433.8MHz on air appears at 0Hz in the recorded file

The file below contains the raw samples as they were transmitted to the computer

18_sdr_uart_433.8MHz_960kHz.bin

uart_decoder.py

The program below uses numpy to decode the data that was transmitted by the Arduino while plotting the signal at every processing step

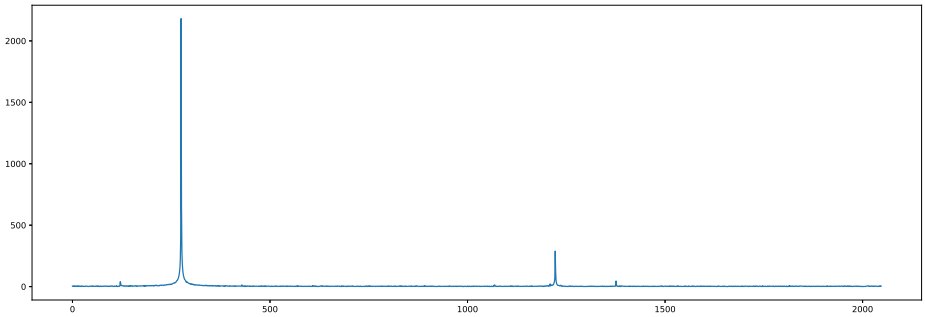
```
1 baseband= samples * lo_sig
2
3 plt.plot(abs(np.fft.fft(baseband[:2048])))
4 plt.show()
```

...

Save the code into the same directory as 18_sdr_uart_433.8MHz_960kHz.bin and run it

The following slides will guide you through the output of the program

signal FFT

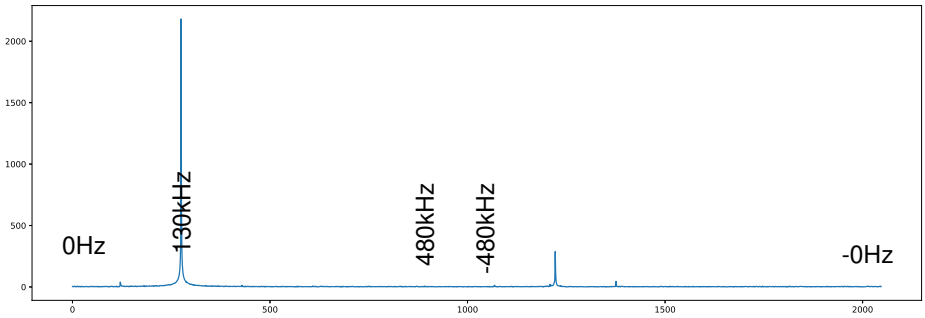



```
1 plt.plot(abs(np.fft.fft(samples[:2048])))
2 plt.show()
```

To get an overview of an RF-signal it makes sense to look at it in the frequency-domain

To get from the time-domain (samples) to the frequency domain the fast fourier transform is applied to the first 2048 samples

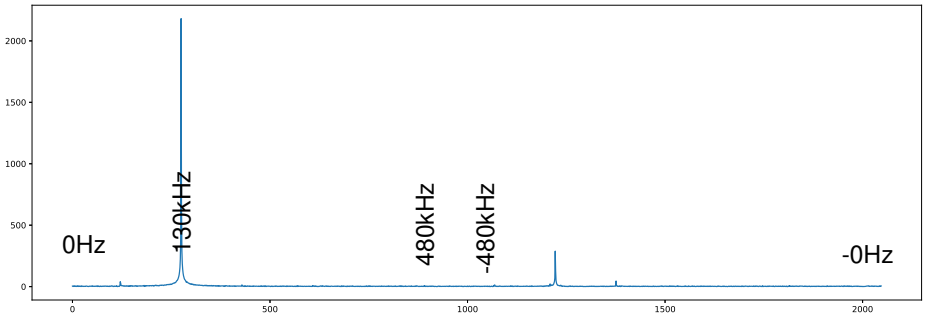
FFT



The raw result of a fourier transformation has a few unintuitive properties:

- There are negative frequencies (this makes sense when working with complex-valued signals)
- The negative frequencies occur in the right half of the output (the output is often reorganized for visualization so that 0Hz is in the middle)

Downmixing



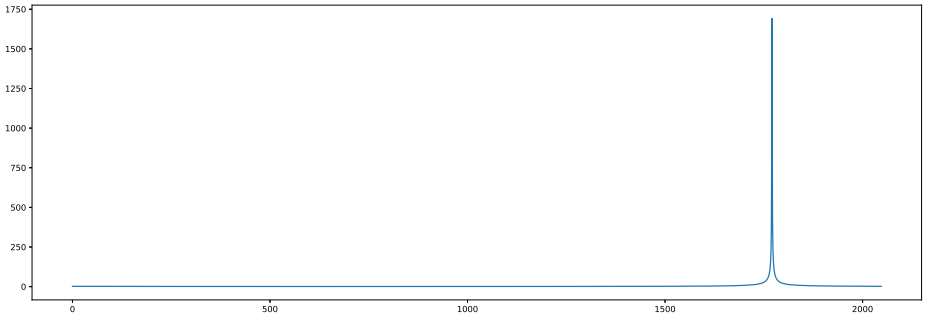
The plot above shows a peak at 130kHz

As the center frequency of the receiver was at 433.8Mhz this means, that the signal was originally sent at

433.8Mhz + 130kHz = 433.93MHz

For further analysis it makes sense to shift the signal to 0Hz, a process called mixing

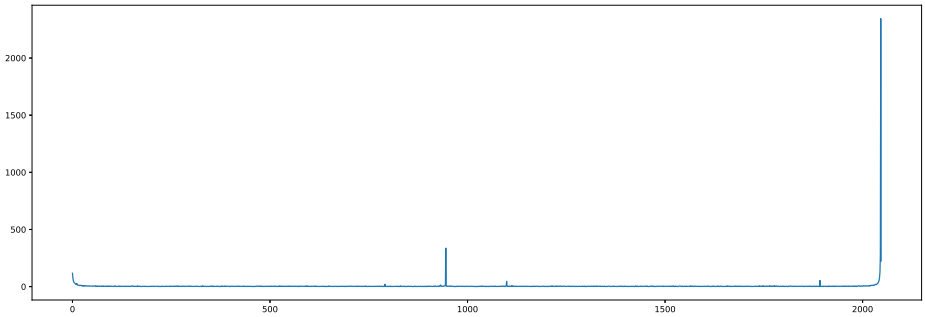
Downmixing



```
offset_freq= -130e3
lo_sig= np.exp(2j * np.pi * offset_freq * t_hp)
```

To perform the mixing a signal with a frequency of -130kHz has to be generated (complex numbers are fun)

Downmixing




```
# Perform the shift
baseband= samples * lo_sig
```

The mixing is then performed by multiplying the receiver-signal with the generated signal
The signal is now centered at 0Hz

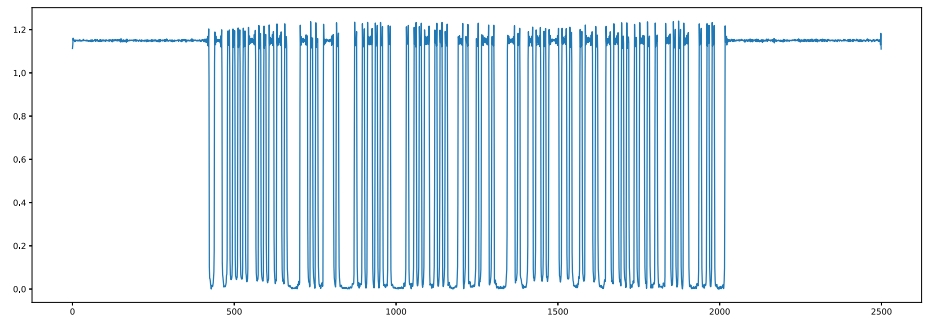
Downsampling

After mixing the signal to 0Hz we can filter away high frequencies and reduce the number of samples

```
lowpass= downsample(baseband)
sample_rate_lp= sample_rate / 100
```

The downsample function performs the filtering and keeps every 100th sample

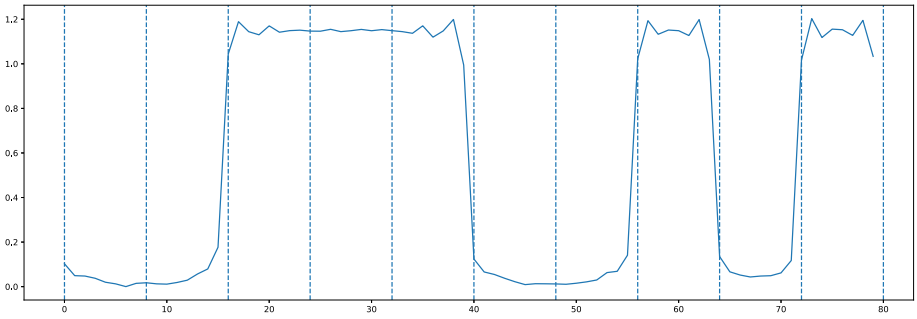
Downsampling




```
abssig= abs(lowpass)
plt.plot(abssig)
```

After downsampling the signal is short enough to be displayed on screen
one can already start to see the UART-encoded data frames

Decoding



To decode the frames one has to find the first sample below a certain threshold

afterwards the bits are decoded by slicing the frame into 10 symbols of equal length, according to the baudrate

if a bit is, on average, below the threshold it counts as `0`, otherwise as a `1`

Decoding

```
>>> decoded_message= decode_message(
...     abssig, 1200, 0.3)
... )
>>> print('Message: {}'.format(decoded_message))
Message: Numpy + Matplotlib
```

When the last frame was processed the complete message is printed

Numpy ❤ Matplotlib