TAMPERE UNIVERSITY OF TECHNOLOGY

PATTERN RECOGNITION AND MACHINE LEARNING

Slide Set 1: Introduction and the Basics of Python

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Signal Processing
Tampere University

Course Organization

- Organized on 3rd period; January – February 2019.
- Lectures every Monday 12–14 (TB109) and Thursday 12-14 (TB109). Exception: Thursday 24.1 is in SA207.
- 10 groups of exercises (sign up at POP).
- More details: **http://www.cs.tut.fi/courses/SGN-41007/**

Course Requirements

1. 60% of exercise assignments solved. For 70 %, you get 1 point added to exam score; for 80 % two points and for 90% three points.
2. Project assignment, which is organized in the form of a pattern recognition competition. The competition is done in groups.
3. The assignment will be opened in Kaggle.com platform soon.
4. Written exam. Max. number of points for the exam is 30 with the following scoring.

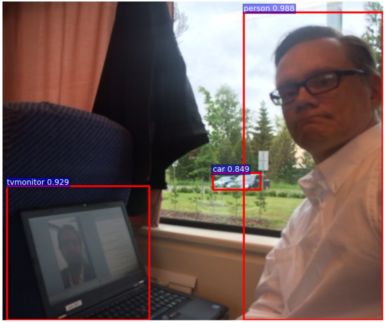
Points	<15	<18	<21	<24	<27	≥27
Grade	0	1	2	3	4	5

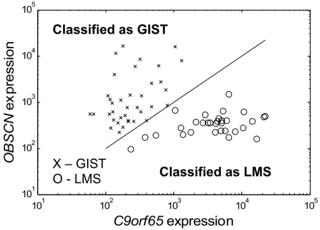
Course Contents

1. **Python:** Rapidly becoming the default platform for practical machine learning
2. **Estimation of Signal Parameters:** What are the phase, amplitude and frequency of this noisy sinusoid
3. **Detection Theory:** Detect whether there is a specific signal present or not
4. **Performance evaluation:** Cross-Validation, Bootstrapping, Receiver Operating Characteristics, other Error Metrics
5. **Machine Learning Models:** Logistic Regression, Support Vector Machine, Random Forests, Deep Learning
6. **Avoid Overlearning and Solve Ill-Posed Problems:** Regularization Techniques

Introduction

- Machine learning has become an important tool for multitude of scientific disciplines.
- Training based approaches are rapidly substituting traditional manually engineered pipelines.
- **Training based** = we show examples of what is interesting and hope the machine learns to do it for us
- **Model based** = we have derived a model of the data and wish to learn the unknown parameters
- A few modern research topics:
    - Image recognition (what is in this image and where?)
    - Speech recognition (what do I say?)
    - Medicine (data-driven diagnosis)



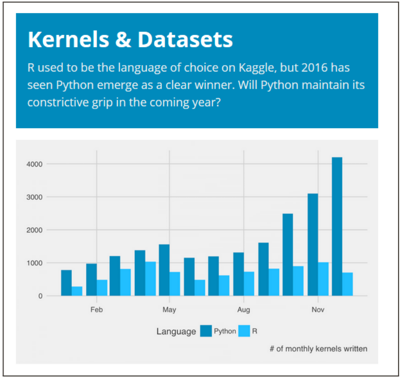


Price et al., "Highly accurate two-gene classifier for differentiating gastrointestinal stromal tumors and leiomyosarcomas," *PNAS 2007*.

Why Python?

- Python is becoming increasingly central tool for data science.
- This was not always the case: 10 years ago everyone was using Matlab.
- However, due to licensing issues and heavy development of Python, scientific Python started to gain its user base.
- Python's strength is in its variability and huge community.
- There are 2 versions: Python 2.7 and 3.6. We'll use the latter.

```
All Python releases are Open Source (see
http://www.opensource.org for
the Open Source Definition).
Historically, most, but not all, Python
releases have also been GPL-compatible;
```



Source: Kaggle.com newsletter, Dec. 2016

Alternatives to Python in Science

Python vs. Matlab	Python vs. R
• Matlab is #1 workhorse for linear algebra. • Matlab is professionally maintained *product*. • Some Matlab's toolboxes are great (Image Processing tb). Some are obsolete (Neural Network tb). • New versions twice a year. Amount of novelty varies. • Matlab is expensive for non-educational users.	• R has been #1 workhorse for statistics and data analysis. [a] • R is great for specific data analysis and visualization needs. • Lots of statistics community code in R. • Python interfaces with other domains ranging from deep neural networks (Tensorflow, pyTorch) and image analysis (OpenCV) to even a fullblown webserver (Django/Flask) [a] **http://tinyurl.com/jynezuq**

- "Matlab is made for mathematicians, R for statisticians and Python for programmers."

Essential Modules

- **numpy**: The matrix / numerical analysis layer at the bottom
- **scipy**: Scientific computing utilities (linalg, FFT, signal/image processing...)
- **scikit-learn**: Machine learning (our focus here)
- **matplotlib**: Plotting and visualization
- **opencv**: Computer vision
- **pandas**: Data analysis
- **statsmodels**: Statistics in Python
- **Tensorflow, keras**: Deep learning
- **PyCharm**: Editor
- **spyder**: Scientific PYthon Development EnviRonment (another editor)

Where to get Python?

- Recommended way: install *Anaconda Python* distribution:
  - **https://www.anaconda.com/download/**
- After installing Anaconda, open "Anaconda prompt", and issue the following commands to set up the libraries:

```
>> conda install python=3.6   # Tensorflow does not support 3.7 yet
>> conda install scikit-learn # Machine learning tools
>> conda install scikit-image # Image processing tools
>> conda install tensorflow   # Or "tensorflow-gpu" if NVidia GPU
>> conda install keras        # Easy front end for tensorflow
```

- Anaconda has also a minimal distribution called *Miniconda*, with which you need to conda `install` more stuff on your own.

Where to get Python?

- ...or in linux:

```
# apt-get install python
# apt-get install python-numpy
# apt-get install python-sklearn
# apt-get install python-matplotlib
# apt-get install spyder
# pip3 install tensorflow
# pip3 install keras
```

The Language

- Python was designed to be a highly readable language.
- Python uses whitespace to delimit program blocks. First you hate it, later you love it.
- All used modules are imported using an `import` declaration.
- The members of a module are referred using the dot: `np.cos([1,2,3])`
- Interpreted language. Also interactive with IPython extensions.

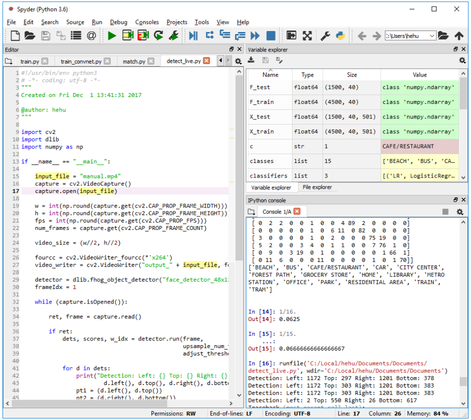
```python
import matplotlib.pyplot as plt
import numpy as np
from sklearn.linear_model import Ridge
from sklearn.linear_model import Lasso
def get_obs_matrix(x, order = 5):
    """
    Return the observation matrix
    constructed from powers of vector x.
    """
    H = []
    for k in range(order):
        H.append(x**k)
    H = np.array(H).T
    return H
if __name__ == "__main__":
    # generate a noisy sinusoid
    np.random.seed(2015)
    x = np.arange(0,1.01,0.08)
    y = np.cos(2 * 2*pi*x) \
        + 0.35*np.random.randn(x.shape[0])
    y2 = np.cos(1 * 2*pi*x) \
        + 0.35*np.random.randn(x.shape[0])
    x = np.arange(0,1.01,0.04)
```

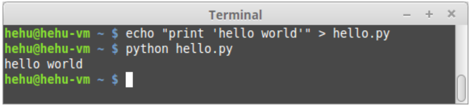
Things to Come

- Following slides will introduce the basic Python usage within scientific computing.
    - **The editor and the environment**
        - *Matlab more product-like than Python*
    - **Linear algebra**
        - *Matlab better than Python*
    - **Programming constructs** (loops, classes, etc.)
        - *Python better than Matlab*
    - **Machine learning**
        - *Python a lot better than Matlab*

Editors

- In this course we use the *Spyder* editor.
- Other good editors: *Visual Studio Code*, *PyCharm*.
- Spyder comes with Anaconda, PyCharm you install on your own. TC303 exercise class has PyCharm.
- Spyder window contains two panes: editor on the left and console on the right.
- F5: Run code; F9: Run selected region.
- Alternatively, you can use whatever editor you like, and run everything on the





Python Basics

- Python code can be executed either from a script file (*.py) or in the interactive mode (just like Matlab).
- For the interactive mode; just execute *python* from the command line.
- Alternatively, *ipython* (if installed) starts Python in a more user-friendly mode:
    - Tab-completion works
    - Many utility functions (*e.g.*, `ls`, pwd, cd)
    - *Magic* functions (*e.g.*, `%run`, `%timeit`, `%edit`, `%pastebin`)

```
Terminal
hehu@hehu-vm ~ $ ipython
Python 2.7.6 (default, Jun 22 2015, 17:58:13)
Type "copyright", "credits" or "license" for more information.

IPython 1.2.1 -- An enhanced Interactive Python.
?         -> Introduction and overview of IPython's features.
%quickref -> Quick reference.
help      -> Python's own help system.
object?   -> Details about 'object', use 'object??' for extra details.

In [1]: ?range
Type:        builtin_function_or_method
String Form:<built-in function range>
Namespace:   Python builtin
Docstring:
range(stop) -> list of integers
range(start, stop[, step]) -> list of integers

Return a list containing an arithmetic progression of integers.
range(i, j) returns [i, i+1, i+2, ..., j-1]; start (!) defaults to 0.
When step is given, it specifies the increment (or decrement).
For example, range(4) returns [0, 1, 2, 3].  The end point is omitted!
These are exactly the valid indices for a list of 4 elements.

In [2]: range(1, 7, 2)
Out[2]: [1, 3, 5]

In [3]:
```

Command `range` *creates a list of integers. Compare to Matlab's syntax* `1:2:6`*.*

Help

- For each command, help is there to refresh your memory:

```
>>> help("".strip) # strip is a member of the string class
Help on built-in function strip:

strip(...)
    S.strip([chars]) -> string or unicode

    Return a copy of the string S with leading and trailing
    whitespace removed.
    If chars is given and not None, remove characters in chars instead.
    If chars is unicode, S will be converted to unicode before stripping
```

- In *ipython*, the shortcut ? is available, too (see previous slide).
- Many people prefer to Google for `python strip` instead; matter of taste.

Using Modules

- Python libraries are called *modules*.
- Each module needs to be imported before use.
- Three common alternatives:
  1. Import the full module: `import numpy`
  2. Import selected functions from the module: `from numpy import array, sin, cos`
  3. Import all functions from the module: `from numpy import *`

```
>>> sin(pi)

NameError: name 'sin' is not defined

>>> from numpy import sin, pi

>>> sin(pi)
1.2246467991473532e-16
```

```
>>> import numpy as np

>>> np.sin(np.pi)
1.2246467991473532e-16
```

```
>>> from numpy import *

>>> sin(pi)
1.2246467991473532e-16
```

Using Modules

A few things to note:

- All methods support shortcuts; *e.g.,* `import numpy as np`.
- Sometimes `import <module>` fails, if the module is in fact a collection of modules. For example, `import scipy`. Instead, use `import scipy.signal`
- Importing all functions from the module is not recommended, because different modules may contain functions with the same name.

```
>>> import scipy
>>> matfile = scipy.io.loadmat("myfile.mat")
AttributeError: 'module' object has no attribute 'io'
```

```
>>> import scipy.io as sio
>>> matfile = sio.loadmat("myfile.mat") # Works OK
```

```
>>> from scipy.io import loadmat
>>> matfile = loadmat("myfile.mat") # Works OK
```

NumPy

- Practically all scientific computing in Python is based on numpy and `scipy` modules.
- NumPy provides a numerical array as an alternative to Python list.
- The list type is very generic and accepts any mixture of data types.
- Although practical for generic manipulation, it is becomes inefficient in computing.
- Instead, the NumPy array is more limited and more focused on numerical computing.

```
# Python list accepts any data types
v = [1, 2, 3, "hello", None]
```

```
# We like to call numpy briefly "np"
>>> import numpy as np

# Define a numpy array (vector):
>>> v = np.array([1, 2, 3, 4])

# Note: the above actually casts a
# Python list into a numpy array.

# Resize into 2x2 matrix
>>> V = np.resize(v, (2, 2))

# Invert:
>>> np.linalg.inv(V)
array([[-2. ,  1. ],
       [ 1.5, -0.5]])
```

More on Vectors

- `np.arange` creates a range array (like `1:0.5:10` in Matlab)

```
>>> np.arange(1, 10, 0.5) # Arguments: (start, end, step)
array([ 1. ,  1.5,  2. ,  2.5,  3. ,  3.5,  4. ,  4.5,  5. ,  5.5,  6. ,
        6.5,  7. ,  7.5,  8. ,  8.5,  9. ,  9.5])

# Note that the endpoint is not included (unlike Matlab).
```

- Most vector/matrix functions are similar to Matlab:

```
>>> np.linspace(1, 10, 5) # Arguments: (start, end, num_items)
array([  1.  ,   3.25,   5.5 ,   7.75,  10.  ])

>>> np.eye(3)
array([[ 1.,  0.,  0.],
       [ 0.,  1.,  0.],
       [ 0.,  0.,  1.]])

>>> np.random.randn(2, 3)
array([[-2.23506417,  0.47311746,  0.05343861],
       [ 1.255074  , -0.03576461,  0.96121907]])
```

Matrices

- A matrix is defined similarly; either by specifying the values manually, or using special functions.

```
# A matrix is simply an array of arrays
# May seem complicated at first, but is in fact
# nice for N-D arrays.

>>> np.array([[1, 2], [3, 4]])
array([[1, 2],
       [3, 4]])

>>> from scipy.linalg import toeplitz, hilbert # You could also " ...import *"
>>> toeplitz([3, 1, -2])
array([[ 3,  1, -2],
       [ 1,  3,  1],
       [-2,  1,  3]])

>>> hilbert(3)
array([[ 1.        ,  0.5       ,  0.33333333],
       [ 0.5       ,  0.33333333,  0.25      ],
       [ 0.33333333,  0.25      ,  0.2       ]])
```

Matrix Product

- Matrix multiplication is different from Matlab. Use ’@’ operator or function `np.matmul`.

```
>>> A = np.array([[1, 2], [3, 4]])
>>> B = np.array([[5, 6], [7, 8]])

>>> A * B # Elementwise product (Matlab: A .* B)
array([[ 5, 12],
       [21, 32]])

>>> A @ B # Matrix product (Python 3.5.2+)
array([[19, 22],
       [43, 50]])

>>> np.dot(A, B) # Functional form; alternatively: np.matmul
array([[19, 22],
       [43, 50]])
```

Indexing

- Indexing of vectors uses the colon notation.
- Below, we extract selected items from the vector `1...10`:

```
>>> x = np.arange(1, 11)
>>> x[0:8:2] # Unlike Matlab, indexing starts from 0
array([1, 3, 5, 7])

# Note: use square brackets for indexing
# Note2: colon operator has the order start:end:step;
# not start:step:end as in Matlab
```

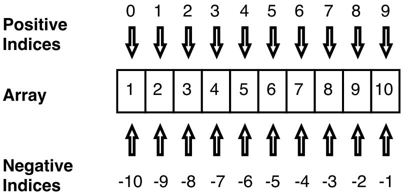
- The start and end points can be omitted:

```
>>> x[5:] # All items from the 5'th
array([ 6,  7,  8,  9, 10])
>>> x[:5] # All items until the 5'th
array([1, 2, 3, 4, 5])
>>> x[::3] # All items with step 3
array([ 1,  4,  7, 10])
```

Indexing

- Negative indices are counted from the end (-1 = the last, -2 = second-to-last, etc.):

```
# Assuming x = np.arange(1, 11):
>>> x[-1]  # The last item
10
>>> x[-3:] # Three last items
array([ 8,  9, 10])
>>> x[::-1] # Items in inverse order
array([10,  9,  8,  7,  6,  5,  4,  3,  2,  1])
```



Indexing

- Also N-dimensional arrays (*e.g., matrices*) can be indexed similarly. This operation is called *slicing*, and the result is a *slice* of the matrix.
- In the example on the right, we extract items on the rows 2:4 = [2,3] and columns 1,2,4 (shown in red).
- Note: the first index is the row; not "x-coordinate".
- This order is called "Fortran style" or "column major" while the alternative is "C style" or "row major".

```
>>> M = np.reshape(np.arange(0, 36), (6, 6))
array([[ 0,  1,  2,  3,  4,  5],
       [ 6,  7,  8,  9, 10, 11],
       [12, 13, 14, 15, 16, 17],
       [18, 19, 20, 21, 22, 23],
       [24, 25, 26, 27, 28, 29],
       [30, 31, 32, 33, 34, 35]])

>>> M[2:4, [1,2,4]]
array([[13, 14, 16],
       [19, 20, 22]])
```

Indexing

- To specify only column or row indices, use ":" alone.
- Now we wish to extract two bottom rows.
- `M[4:, :]` reads "give me all rows after the 4th and all columns".
- In this case, alternative forms would be, *e.g.*, `M[-2:, :]` and `M[[4,5], :]`.

```
>>> M = np.reshape(np.arange(0, 36), (6, 6))
array([[ 0,  1,  2,  3,  4,  5],
       [ 6,  7,  8,  9, 10, 11],
       [12, 13, 14, 15, 16, 17],
       [18, 19, 20, 21, 22, 23],
       [24, 25, 26, 27, 28, 29],
       [30, 31, 32, 33, 34, 35]])

>>> M[4:, :]
array([[24, 25, 26, 27, 28, 29],
       [30, 31, 32, 33, 34, 35]])
```

N-Dimensional arrays

- Higher-dimensional arrays are frequently encountered in machine learning.
- For example, a set of 1000 color images of size $w \times h = 128 \times 96$ is represented as a $1000 \times 96 \times 128 \times 3$ array.
- Here, dimensions are: image index, y-coordinate, x-coordinate, color channel.

```
# Generate a random "image" array:
>>> A = np.random.rand(1000, 96, 128, 3)

# What size is it?
>>> A.shape
(1000L, 96L, 128L, 3L)

# Access the pixel at $x = 3$, $y = 4$ of 2nd color channel
# of the 2nd image
>>> A[1, 4, 3, 2]
0.9692199423337374

# Request all color channels at that location:
>>> A[1, 4, 3, :]
array([0.19971581, 0.30404188, 0.96921994])

# Request a complete 96x128 image:
>>> A[1, :, :, :]
array([[[0.40978563, 0.86893457, 0.30702007], ...
0.81794195]]])

# Equivalent shorter notation:
>>> A[1, ...]
array([[[0.40978563, 0.86893457, 0.30702007], ...
0.81794195]]])
```

Functions

- Functions are defined using the `def` keyword.
- Function definition can appear anywhere in the code.
- Functions can be imported to other files using `import`.
- Function arguments can be *positional* or *named* (see code).
- Named arguments improve readability and are handy for setting the last argument in a long list.

```
# Define our first function
def hello(target):
    print ("Hello " + target + "!")

>>> hello("world")
Hello world!

>>> hello("Finland")
Hello Finland!

# We can also define the default argument:
def hello(target = "world"):
    print ("Hello " + target + "!")

>>> hello()
Hello world!

>>> hello("Finland")
Hello Finland!

# One can also assign using the name:

>>> hello(target = "Finland")
Hello Finland!
```

Loops and Stuff

```
for lang in ['Assembler', 'Python', "Matlab", 'C++']:
    if lang in ["Assembler", "C++"]:
        print ("I am ok with %s." % (lang))
    else:
        print ("I love %s." % (lang))
```

```
I am ok with Assembler.
I love Python.
I love Matlab.
I am ok with C++.
```

```
# Read all lines of a file until the end

fp = open("myfile.txt", "r")
lines = []

while True:

    try:
        line = fp.readline()
        lines.append(line)
    except:
        # File ended
        break

fp.close()
```

- Loops and other usual programming constructs are easy to remember.
- `for` can loop over anything *iterable*, such as a list or a file.
- In Matlab, appending values to a vector in a loop is not recommended. Python lists are actual lists, so appending is fine.

Example: Reading in a Data File

- Suppose we need to read a csv file (text file with Comma Separated Values) into Python.

```
Sample_ID,M1;M2;M3;M4;M5;M6;M7;M8;M9;M10;M11;M12;M1
S0;0.063915;0.033242;0.018484;0.0086177;0.035629;0.
S1;0.025409;0.051085;0.056305;0.021738;0.02741;0.01
S2;0.025536;0.036123;0.054195;0.009735;0.027521;0.0
S3;0.012817;0.029652;0.07929;0.050677;0.039737;0.05
S4;0.019846;-0.010577;-0.0075045;0.019042;0.068786;
```

- The file consists of 216 rows (samples) with 4000 measurements each.
- We will write file reading code from scratch.
- Alternatively, many modules contain csv-reading functions
  - `numpy.loadtxt`
  - `numpy.genfromtxt`
  - `csv.reader`
  - `pandas.read_csv`

Example: Reading in a Data File

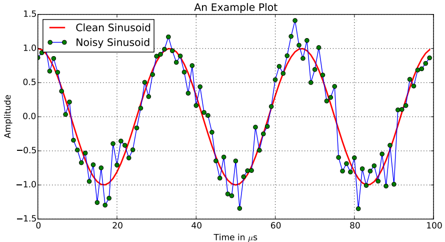
```python
import numpy as np

if __name__ == "__main__":

    X = [] # Rows of the file go here

    # We use Python’s with statement.
    # Then we do not have to worry
    # about closing it.

    with open("ovarian.csv", "r") as fp:

        # File is iterable, so we can
        # read it directly (instead of
        # using readline).

        for line in fp:

            # Skip the first line:
            if "Sample_ID" in line:
                continue
```

```python
            # Otherwise, split the line
            # to numbers:
            values = line.split(";")

            # Omit the first item
            # ("S1" or similar):
            values = values[1:]

            # Cast each item from
            # string to float:
            values = [float(v) for v in values]

            # Append to X
            X.append(values)

    # Now, X is a list of lists. Cast to
    # Numpy array:
    X = np.array(X)

    print ("All data read.")
    print ("Result size is %s" % (str(X.shape)))
```

Visualization

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

N = 100
n = np.arange(N) # Vector [0,1,2,...,N-1]
x = np.cos(2 * np.pi * n * 0.03)
x_noisy = x + 0.2 * np.random.randn(N)

fig = plt.figure(figsize = [10,5])

plt.plot(n, x, 'r-',
         linewidth = 2,
         label = "Clean Sinusoid")

plt.plot(n, x_noisy, 'bo-',
         markerfacecolor = "green",
         label = "Noisy Sinusoid")

plt.grid("on")
plt.xlabel("Time in $\mu$s")
plt.ylabel("Amplitude")
plt.title("An Example Plot")
plt.legend(loc = "upper left")

plt.show()
plt.savefig("../images/sinusoid.pdf",
            bbox_inches = "tight")
```

- The `matplotlib` module is our plotting library.
- Function names are often similar to Matlab.
- Usually you want to "`import matplotlib.pyplot`".
- Alternatively, "`from matplotlib.pylab import *`" makes the environment very similar to Matlab.
- Code also in **https://github.com/mahehu/SGN-41007**



Another Example

- Even rather complicated graphics are easy to generate using Matplotlib.
- The code for the attached diagram is shown in **https://github.com/mahehu/SGN-41007**.