Deep Learning

Exercise 1: Perceptron Learning in Python

Room: **BIN-1-B.01**
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Friday, February 25, 2022, 10:15 – 11:45

Outline

Outline

1. Using Python in this Exercise
    - Running Python
    - Gathering Implementations
    - Local Installation

Running Python

Console

- Start Python: `python`
- Code some operations: `4*5`
- Getting help: `help(print)`

Advantage

Interactive, quick

Disadvantage

Bad for complicated code

Script

- Edit `script.py` with text editor
- Results are not printed
  → use `print(4*5)` to output
- Run script: `python script.py`

Advantage

Easily repeatable

Disadvantage

Two-step process, non-interactive

Running Python

JuPyter Notebooks

- Combination of text (explanation) and code
  → Markdown markup language including headers, math, hyperlinks, ...
- Allows easy interaction and debugging by running separate cells
- Integrated in many editors (e.g. Visual Studio Code)
- Online documentation available http://docs.jupyter.org
- Supported by Google Colab http://colab.research.google.com
- Drawback: not useful for larger projects

Assignment Support

All assignments are accompanied by a Jupyter notebook template

Gathering Implementations

Working Teams

- Working in teams allowed / recommended
  - → Team size ~2-4 students
- Each team provides one (partial) solution
  - → In Microsoft Forms, no paper submission
  - → Solutions are **not graded**

Microsoft Forms

- Questionnaire for each task / subtask
- Provide source code (copy from Jupyter notebook)
- Partial answers allowed
  - → If you are unsure, you can skip parts or the whole form

Local Installation

Conda Installation

- Install Conda for your operating system:
  http://docs.conda.io/en/latest/miniconda.html
- Optional: create and activate local environment
  - Create environment: `conda create -name DL python=3.8`
  - Activate environment: `conda activate DL`
- Install packages
  - `conda install numpy scipy scikit-learn matplotlib jupyter`
- Run from console (opens in web browser): `jupyter notebook`
  https://realpython.com/jupyter-notebook-introduction
- Visual Studio Code setup:
  https://code.visualstudio.com/docs/datascience/jupyter-notebooks

Outline

2. Assignment 1: Perceptron Learning

Assignment 1: Perceptron Learning

Task 1: Data Generation

- Generate 2D data $X = \{\vec{x}^{[1]}, \vec{x}^{[2]}, \ldots, \vec{x}^{[N]}\}$ with $N = 100$
- 2 classes: $t^{[n]} \in \{-1, 1\}$

  $\rightarrow$ 2 normal-distributed datasets with means $\vec{\mu}$ and standard deviations σ

Task 2: Parameter Selection

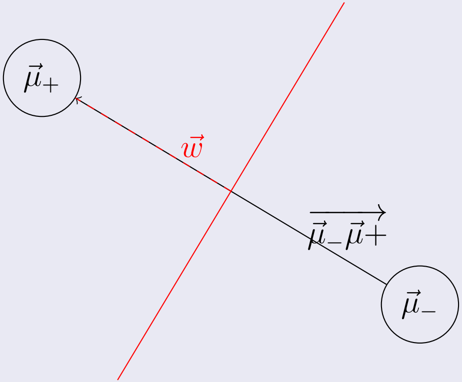
- Select means $(\vec{\mu}_+, \vec{\mu}_-)$ and (σ_+, σ_-) wisely to create separable data
- Analytically define line $\vec{w}$ to separate positive and negative samples

Test 1: Separability Test

- Given data (X, T) and line $\vec{w}$ check if $\vec{w}$ separates (X, T)
- Test: $\forall n : \vec{w}^{\mathrm{T}} \vec{x}^{[n]} t^{[n]} > 0$

Assignment 1: Perceptron Learning

Hint for Parameter Selection



Data and Parameter Selection

- Use line in normal form $w_0 + w_1x_1 + w_2x_2$
- The normal (w_1, w_2) points perpendicular to the line
- The optimal separating line is perpendicular to $\overrightarrow{\vec{\mu}_-\vec{\mu}_+}$
- Select w_0 such that the line is in the middle of $\vec{\mu}_-$ and $\vec{\mu}_+$

Assignment 1: Perceptron Learning

Task 3: Perceptron

- Implement perceptron

Task 4: Perceptron Learning

1. Given: initial $\vec{w}$ and data (X, T)
2. Choose a training sample $(\vec{x}, t)$
3. Predict its class $y = g(\vec{w}^{\mathrm{T}}\vec{x})$
4. If wrongly classified $(y \cdot t < 0)$
   $\rightarrow$ Update weights: $\vec{w} = \vec{w} + t \cdot \vec{x}$
5. Repeat for next samples
6. Return optimized $\vec{w}$

Test 2: Sanity Check

- What happens when you start with an already separating line?

Task 5: Random weights

- Create random weight vector $\vec{w} \in [-1, 1]^3$.

Task 6: Learn Separation

- Apply perceptron learning on random weights

Assignment 1: Perceptron Learning

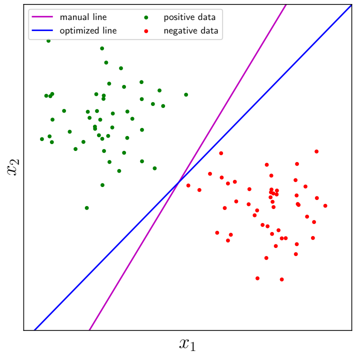
Test 3: Check Result

- Verify that learning was successful

Task 7: Plots

- Plot colored data points from task 2
- Plot manual line from task 2
- Plot optimized line from Task 6
- Beautify plots

Exemplary Solution



Outline

Datatypes and Operations

Dynamically Typed Numbers

- Boolean:
  - `k = True`
- (Signed) integer:
  - Simple: `a = -42`
  - Long: `b = 12345678901234567890`
  - Hex: `c = 0x6AfEb5`
- Float (IEEE 754 double):
  - Simple: `pi = 3.14159265`
  - Scientific: `sci = 1.4142e-5`
- Complex numbers (128 bit):
  - Simple: `cplx = -1.5 + 3.2j`

Operations

- Boolean:
  - `not`, `and`, `or`
- Numerical:
  - `+`, `-`, `*`, `/`, `//`, `%`, `**`
  - `5/2 = 2.5`, but `5//2 = 2`
    Different in Python 2!
  - Modulo: `24 % 10 = 4`
  - Power: `5 ** 2 = 25`
- Assignment:
  - `=`, `+=`, `-=`, `/=`, `//=`, `%=`, `**=`
- Conversion:
  - `float(b)`, `int(pi)`

Datatypes in Python

Complex Datatypes

- String (immutable):
  - `s1 = "Hello"`
  - `s2 = 'world'`
  - `s3 = """Multiline string with exact interpretation"""`
- List, Tuple (immutable)
  - `x = [-1e-5, 'text', s1]`
  - `y = (s2,)`
- Dictionary
  - `d = {"a" : 0.4, 17 : c}`
- Nonetype `None`

Operations

- Concatenation:
  - String: `"Hello" + ' world!'`
  - List: `x + [y]` and `x += [y]`
  - Tuples and lists: ~~`[1] + (2,)`~~
- Multiplication:
  - String: `"ab"*4`
  - List/Tuple: `[2]*10`, `('o',)*10`
- Indexing:
  - Dictionary: `d['a']`, `d[1.5]='x'`
  - List/Tuple: `y[0]`, `x[2]=None`
  - Range: `x[1:3]`, `x[:2]`, `x[2:]`
  - Negative: `x[-1]`, `x[-2:]`

Datatypes in Python

List Manipulation

- `append(x)` appends element `x`
- `extend([x])` appends iterable
- `insert(i, x)` inserts `x` at `i`
- `remove(x)` removes `x`
  → only if exists, first occurrence
- `pop(i)` removes and returns element at index `i`
- `del` removes specific index
  → different syntax
- `clear()` removes all elements

Example

```
# create initial list
data = [0, "one", 2., 'three', [4]]

# append values
data.append("5")
data.extend((6, 7.))

# insert values
data.insert(0, -1)
data[0:0] = ["-3", -2.]

# delete values
data.remove("three")
data.pop(1)
data.pop(-2)
del data[3]
```

Datatypes in Python

Type checking via `type`

- `type(1)` → `<class 'int'>`
- `type(1.)` → `<class 'float'>`
- `type(1j)` → `<class 'complex'>`
- `type({})` → `<class 'dict'>`
- `type(())` → `<class 'tuple'>`
- `type((1))` → `<class 'int'>`
- `type((1,))` → `<class 'tuple'>`
- `type([])` → `<class 'list'>`
- `type("")` → `<class 'str'>`

Type testing via `isinstance`

- `isinstance(1, int)` → `True`
- `isinstance(1, float)` → `False`
- `isinstance(1., float)` → `True`
- `isinstance(1., (int, float))` → `True`
- `isinstance('', str)` → `True`
- `isinstance([], str)` → `False`
- `isinstance((1), tuple)` → `False`
- `isinstance((1,), tuple)` → `True`

Control Flow

Indentation

- Blocks have same indentation
- Default: 4 spaces
- Mixing tabs and spaces
  - → Strongly discouraged
  - → Setup editor to insert spaces

`if` Statements

```
if Boolean Condition:
    Code for True Condition
else:
    Optional Code for False Cd.
```

Control Flow

while Loops

```
while Boolean Condition:
    if Skip Condition:
        continue
    Repeated Code
    if Additional Condition:
        break
else:
    Code when exited normally
```

while Loop Example

```
data = [0, [1], "two", 3., '4', -5]
index = 0
while index < len(data):
    if isinstance(data[index], list):
        continue

    number = float(data[index])
    print (number*2)
    index += 1

    if data[index] < 0:
        break

else:
    print ("Success!")
```

Control Flow

while Loops

```
while Boolean Condition:
    if Skip Condition:
        continue
    Repeated Code
    if Additional Condition:
        break
else:
    Code when exited normally
```

Coding

Find three issues with this code.

while Loop Example

```
data = [0, [1], "two", 3., '4', -5]
index = 0
while index < len(data):
    if isinstance(data[index], list):
        continue

    number = float(data[index])
    print (number*2)
    index += 1

    if data[index] < 0:
        break

else:
    print ("Success!")
```

Control Flow

while Loops

```
while Boolean Condition:
    if Skip Condition:
        continue
    Repeated Code
    if Additional Condition:
        break
else:
    Code when exited normally
```

Coding

Find three issues with this code.

infinite loop, `float([1])`, `"two" < 0`

while Loop Example

```
data = [0, [1], "two", 3., '4', -5]
index = 0
while index < len(data):
    if isinstance(data[index], list):
        continue

    number = float(data[index])
    print (number*2)
    index += 1

    if data[index] < 0:
        break

else:
    print ("Success!")
```

Control Flow

`for` Loops

```
for item in iterable:
    if Skip Condition:
        continue
    Code using item
    if Additional Condition:
        break
else:
    Code when exited normally
```

Iterables and Examples

- Lists/Tuples
  - → Elements: `for e in [1,4,7,10]`
- Ranges:
  - → `for i in range(0,20,2)`
  - ⇒ start, end (exclusive), stepwidth
- Enumerations:
  - → `for i, e in enumerate([1,4,7,10])`
  - ⇒ Tuple Unboxing
- Dictionaries
  - → Keys: `for k in {1:2, 3:4}`
  - → Both: `for k, v in {1:2, 3:4}.items()`

Control Flow

List Comprehensions

- Turn one list into another
- Filter elements (optional)
- Nested List Comprehensions

Definition

```
[f(x) for x in src if cond(x)]
```

Examples

```
squares = [x**2 for x in range(10)]
odds = [x for x in range(10) if x % 2]

triang = [[x for x in range(10) if x >= y]
             for y in range(10)]
```

Dictionary Comprehensions

- Create dictionaries
- Filter elements (optional)
- Nested comprehensions

Definition

```
{key : val for ... if ...}
```

Examples

```
squares = {x : x**2 for x in range(10)}
halves = {x : x//2 for x in range(10)
                      if x % 2}

inv = {v : k for k, v in {...}.items()}
```

Functions

Function Definition

```
def func_name(arguments, keywords):
    Code
    return ...
```

Arguments

- Required to be specified
- No datatype is required

Keywords

- Arguments with default values
  → Syntax: `name=value`
- Warning: default values `[]` or `{}`

Function Call Examples

```
def func1(data, opt=None):
    if opt is None:
        print("data is", data)
    else:
        return data

func1(27)
  -> prints "data is 27"
  -> returns None

func1(27, True)
  -> returns 27

func1(opt = False, data = 27)
  -> returns 27
```

Functions

Generator Function

- To be used, e.g., with `for` loop
- Returns samples one by one

  → Useful for large collections

Function Definition

```
def func_name(arguments, keywords):
    while ...:
        yield ...
```

Predefined Generators

- `range`, `enumerate`
- `dict.keys()`, `dict.items()`

Generator Example

```
def sup(it1, it2):
    for v1 in it1:
        for v2 in it2:
            yield v1, v2


for t in sup("ab", range(2)):
    print(t)


('a', 0)
('a', 1)
('b', 0)
('b', 1)
```

Classes and Objects

Function Definition

```
class ClassName(parents):
    member = None

    def __init__(self, params):
        super(ClassName, self).__init__()
        Initialization of self

    def method(self, params):
        Can use self and params
        return ...

    @staticmethod
    def static(params):
        Cannot use self
        return ...
```

Members

- Prior definition optional
- Access through `self.member`
- Publicly accessible

Constructor

- Base class constructor
- Initializes object (`self`)

Functions

- First parameter: `self`
- Special function `__call__`

Classes and Objects

Example

```
class AddN(object):
    def __init__(self, n=1):
        super(AddN, self).__init__()
        self.n = n

    def __call__(self, x):
        return x + self.n

    def squared(self, x):
        return x**2 + self.n

    def sequence(self, x):
        for n in range(self.n):
            yield x + n
```

Example (Contd.)

```
add1 = AddN(n=1)
print(add1.squared(5))
print(add1(5))

add1.n = 4
add1.unused = None
print(add1.squared(5))

for n in add1.sequence(10):
    print(n)
```

Classes and Objects

Objects in Python

In Python (almost) everything is an object

Immutable Objects

```
def modify(x):
    x += 1

y = 10
modify(y)
print(y) -> 10
```

Mutable Objects

```
def append(x):
    x.append(1)

y = [10]
append(y)
print(y) -> [10,1]
```

Function Objects

```
def sqr(x):
    return x**2

def apply(f, data):
    return f(data)

print(apply(sqr, 5))
print(apply(add1, 5))
```

Exceptions

Exception Handling

```
try:
    Code

except Exception1 as ex:
    print(ex)
    raise Exception() from ex

except (Exception2, Exception3):
    Handle exception
    raise

finally:
    Always executed
```

Types of Exceptions

- Base class: `Exception`
- `SyntaxError`
- `ArithmeticError`
- `ValueError`
- `IndexError`, `KeyError`
- `MemoryError`
- `StopIteration`, `SystemExit`
- Own Exceptions
  → derive from `Exception`

String Formatting

Old Types of String Formatting

- The `%` syntax:
  → `"name: %s; age: %d" % ("John", 42)`
- The `format` syntax:
  → `"name: {}; age: {}".format("John", 42)`
  → `"name: {name}; age: {age}".format(age=42, name="John")`

Python `f`-Strings

- Special syntax `f""` or `F""`
- Evaluates expressions in `{}`
- Number formatting `f"{n:w.p}"`
  → number, width, precision

Example

```
data = {"name" : "John", "age" : 42}
print(f"name: {data['name']}; age: {data['age']}")

x = 3.14159265
print(f"pi = {x: 3.4}")
```

File I/O

The `open` function

- Signature: `open(name, mode, ...)`
- Filenames `"C:/path/to/file.txt"`
- Opening modes:
  - `'r'`ead, `'w'`rite, `'a'`ppend
  - `'t'`ext: `str`, `'b'`inary: `bytes`

The `with` Statement

- Ensures closure of object
- Syntax for files:

  `with open(...) as file:`

Example

```
# write file
with open("test.txt", 'wt') as file:
    for x in range(1,11):
        file.write(f"{x},{x**2}\n")

# read file
with open("test.txt", 'rt') as file:
    for line in file:
        x, y = line.rstrip().split(',')
        print(x, y)
```

Outline

4. Modules
   - Builtin Modules
   - Vector Math with `numpy` and `scipy`
   - Scientific Plotting with `matplotlib`

Modules

Modules in Python

- Library containing related functionality
- Can contain submodules, classes, functions
- Need to be `import`ed before usage

Preferred

```
import os
os.listdir(".")
```

Often Seen

```
from os import listdir
listdir(".")

import numpy as np
np.ndarray(5)
```

Highly Discouraged

```
from os import *
listdir(".")

from os import listdir as ls
ls(".")
```

Builtin Modules

Operating System `os`

- Directory handling
  → `getcwd`, `chdir`, `listdir`, `mkdir`, `rmdir`, `walk`
- File handling
  → `link`, `rename`, `remove`, `chown`, `chgrp`
- Filename handling `os.path`
  → `join`, `split`, `splitext`, `abspath`, `exists`, `isdir`
- Process handling
  → `fork`, `spawn`, `exec`, `nice`, `wait`, `kill`

Python System `sys`

- Command line arguments `argv`
- Search path `path`
- Console in/output
  → `stdin`, `stdout`, `stderr`

Mathematics `math`

- Constants: `pi`, `e`, `inf`, `nan`
- Rounding: `fabs`, `ceil`, `floor`
- Exponential: `exp`, `log`, `pow`, `sqrt`
- Trigonometrical: `sin`, `sinh`, `asin`

Builtin Modules

Random Numbers `random`

- Single value:
  → `random`, `uniform`, `gauss`, `randint`, `choice`
- Sequences
  → `shuffle`, `sample`
- Reproducibility: `seed`

Serealization `pickle`

- Writing: `dump`, `dumps`
- Loading: `load`, `loads`

Other Modules

- Temporary files: `tempfile`
- Compression: `tarfile`, `zipfile`
- Data Formats: `csv`, `json`, `html`, `pandas`
- Database Interface: `sqlite3`
- Argument parser: `argparse`, `getopt`
- Console/file logging: `logging`
- Parallelization: `multiprocessing`, `subprocess`, `threading`
- Communication: `urllib`, `http`, `ftplib`

Vector Math with `numpy` and `scipy`

Multi-dimensional Arrays `ndarray`

- Creating in `dims=(3,6,4)`:
  - → empty: `ndarray(dims, dtype)`
  - → zeros: `zeros(dims, dtype)`
  - → ones: `ones(dims, dtype)`
  - → from data: `array(data, dtype)`
  - → random: `random.random(dims)`
- Indexing:
  - → Single Element: `x[0,1,-2]`
  - → Slicing: `x[:2,:,2:]`
  - → Step: `x[1:3:2, 1::3, ::-1]`

Array Attributes

- Dimensionality: `shape`
- Elements: `size`
- Data type: `dtype`

Array Methods

- Fill with value: `fill`
- Deep copy: `copy`
- Change shape: `reshape`
- Change to 1D: `flatten`
- Transpose: `transpose`

Vector Math with numpy and scipy

Element-wise Operations on Arrays

- Arithmetic: `+`, `-` , `*`, `/`, `//`, `%`
- Assign: `+=`, `-=` , `*=`, `/=`, `//=`, `%=`
- Comparison: `<`, `>`, `<=`, `==`
  - ⇒ Boolean arrays

Broadcasting

- Repeating elements to higher dimensions
  - → Single value: `x += 1.`, `x > 0`
  - → Last dimension: `x * (1,4,3,2)`
- Dimensions must be equal or 1

Eamples

```
x = numpy.array([[1,2,3,4],
                 [5,6,7,8]])
# boolean arrays
x < 4
x == 4

# simple broadcasting
y = x * -1.
x *= -1.

# complex broadcasting
z = x * [[2],
         [-1]]
```

Vector Math with numpy and scipy

Arrays Reductions

- Reduce specific dimension (axis)
- min, max, argmin, argmax
- sum, cumsum, mean, std
- For Boolean arrays: any, all

Array Modifications

- Sorting: sort, argsort
- Inserting: insert, append
- Concatenate: vstack, hstack
- Dimensions: squeeze, expand_dims

Eamples

```
x = numpy.array([[1,2,3,4],
                 [5,6,7,8]])
# minimum
x.min()
numpy.min(x, axis=1)

# sum and std
x.sum(axis=0)
numpy.std(x)

# boolean
(x > 8).any()

# sorting
numpy.argsort(x, axis=0)
```

Vector Math with numpy and scipy

Basic Linear Algebra

- Matrix multiplication `numpy.dot`
- Vector multiplication `numpy.inner`, `numpy.outer`
- Norms `scipy.linalg.norm`
- Inverse `scipy.linalg.inv`
- Distances `scipy.spatial.distance`
  → `euclidean`, `cosine`, `cdist`

Example

```
import numpy, scipy.spatial
# create two arrays
x = numpy.array([1.,2.,3.])
y = numpy.random.normal(size=3)

# compute vector prodcts
numpy.inner(x,y)
numpy.dot(x,y)
numpy.outer(x,y)

# normalize vector
x /= scipy.linalg.norm(x)

# compute cosine distance
scipy.spatial.distance.cosine(x,y)
```

Scientific Plotting with matplotlib

Plotting Functions

- `plot([x],y,[fmt],[label])`
  - → `x` and `y`: coordinates to plot
  - → `fmt`: color: `"rgbkmcy"` and style `".+xosd-:"`
  - → `label`: string for legend
- `legend([labels],[loc])`
  - → `loc = "upper left", "center", "best"`
- Limit axes `xlim`, `ylim`
- Axis labels `xlabel`, `ylabel`
- Save to file: `savefig`

Example

```
import numpy
from matplotlib import pyplot

# create data
x = numpy.arange(-5,5.001,0.1)
target = numpy.cos(x)
data = target + numpy.random.normal(0, .2, x.shape)

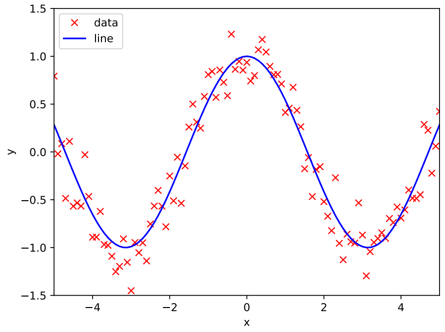
# plot data points and line
pyplot.plot(x, data, "rx", label="data")
pyplot.plot(x, target, "b-", label="line")

# limit axes and provide labels
pyplot.xlim((-5,5)); pyplot.ylim((-1.5,1.5))
pyplot.xlabel("x"); pyplot.ylabel("y")

# create legend and write to file
pyplot.legend(loc="upper left")
pyplot.savefig("Example.pdf")
```

Scientific Plotting with `matplotlib`

Example Plot



Example

```
import numpy
from matplotlib import pyplot

# create data
x = numpy.arange(-5,5.001,0.1)
target = numpy.cos(x)
data = target + numpy.random.normal(0, .2, x.shape)

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pyplot.plot(x, data, "rx", label="data")
pyplot.plot(x, target, "b-", label="line")

# limit axes and provide labels
pyplot.xlim((-5,5)); pyplot.ylim((-1.5,1.5))
pyplot.xlabel("x"); pyplot.ylabel("y")

# create legend and write to file
pyplot.legend(loc="upper left")
pyplot.savefig("Example.pdf")
```

Scientific Plotting with `matplotlib`

Surface Plots

- Create `fig = figure([figsize])`
- Create subplots

  `fig.add_subplot(RCI, [projection])`

  → Rows, Columns, Index (one-based)
- Single 3D subplot

  `ax = fig.add_subplot(111, projection="3d")`
- Create 3D data:

  `xx, yy = numpy.meshgrid(x,y)`, `zz`
- Surface plot:

  `ax.plot_surface(xx, yy, zz)`

Example

```
# create data
x = numpy.arange(-5., 5.001, 0.1)
y = numpy.arange(-3., 3.001, 0.1)
xx, yy = numpy.meshgrid(x,y)
zz = numpy.sin(xx) * yy

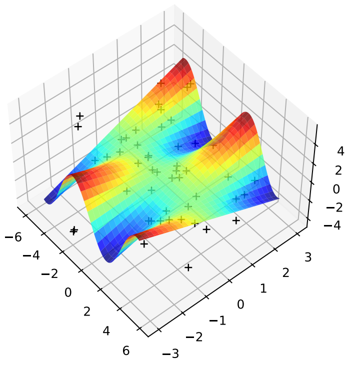
# surface plot
fig = pyplot.figure()
ax = fig.add_subplot(111, projection='3d',
                     azim=-40, elev=50)
ax.plot_surface(xx, yy, zz, cmap="jet", alpha=.8)

# single point plot in 3D
pts = numpy.random.normal(0, (3,1.5,3), (50,3))
ax.plot(pts[:,0], pts[:,1], pts[:,2], "kx")

# write to file
pyplot.savefig("Surface.pdf")
```

Scientific Plotting with matplotlib

Example Surface Plot



Example

```
# create data
x = numpy.arange(-5., 5.001, 0.1)
y = numpy.arange(-3., 3.001, 0.1)
xx, yy = numpy.meshgrid(x,y)
zz = numpy.sin(xx) * yy

# surface plot
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