4^{th} 2017/18 **GouTP @ SCEE**

- *About:* **Python introduction for MATLAB users**
- *Date:* 18th of January 2018
- *Who:* Lilian Besson

What's a *"GouTP"* ?

- **Internal monthly technical training session** 📅
- Usually: *Thursday 3pm* 🕒 - *3:30pm* 🕞
- With ☕ coffee and 🍪 sweets: we relax while training !

> Initiative of Quentin and Vincent 👏 in January 2017...
> Continued by Rémi, Rami and Lilian 👌 !

Not only @ SCEE ?

- Currently open to the *FAST* and *AUT* teams

Agenda for today [30 min]

1. What is Python [5 min]
2. Main differences in syntax and concepts [5 min]
3. 5 Examples of problems solved with Python [15 min]
4. Where can you find more information ? [5 min]

1. What is Python 🐍 ?

- Developped and popular from the last 25 years
- Open-source and free programming language
- *Interpreted*, multi-platform, imperative and object-oriented
- Designed and acknowledged as *simple to learn and use*
- Used worldwide: research, data science, web applications etc

Ressources

- **Website**: python.org for the language & pypi.org for modules
- Documentation 🖩 : docs.python.org
  (🇫🇷 also docs.python.org/fr/3 - 🐌 the translation in progress)

Comparison with MATLAB

	Python 😀	**MATLAB** 😢
Cost	Free ✌️	Hundreds of **€ / year**
License	Open-source	1 year user license (no longer after your PhD!)
Comes from	A non-profit foundation, and "the community"	MathWorks company
Scope	Generic	Numeric only
Platform	Any 💻 📱	Desktop only 💻
Usage	Generic, worldwide 🌎	Research in academia 🎓 and industry 🏭

> But Python is not perfect…

	Python 😢	**MATLAB** 😃
Modules	Different good solutions (`conda`, `pip`)	Toolboxes already included
IDE	Many possibilities, have to chose one (*Spyder*)	Good IDE already included
Support?	Community (StackOverflow, IRC, mailing lists etc)	By MathWorks ?
Performance	Interpreted, not so fast (check *Pypy* for speed)	Faster (but worse than C/Java/Julia)
Documentation	👌 OK but very diverse	👌 OK and inline

How to install Python ? ⬇️

- On Linux and Mac OS: already installed!
- On Windows:
  - Use the full installer from anaconda.com/download (✨)
  - Or the default installer from python.org/downloads/windows
- Takes about 10 minutes… and it's free ✌️ !

> ⚠️ Choose **Python 3** (currently 3.6.4) **not 2 !**
> ⚠️ Python 2 will stop 🕒 in less than 3 years (pythonclock.org)

My suggestions for Python

- Use **Anaconda** to install (and upgrade) Python and packages
- Use **IPython** for the command line (✨ awesome features!)
- Use:
  - **Spyder** for your IDE if you like the MATLAB interface (installed in Anaconda, or `pip install spyder`)
  - PyCharm if you want "the most powerful Python IDE ever"
  - Or a good generic text editor + a plugin for Python (Emacs, Vim, Atom, SublimeText, **Visual Studio Code**…)
- Use **Jupyter notebooks** to write or share your experiments (jupyter.org, ex: my github.com/Naereen/notebooks collection)

> More suggestions: pierreh.eu/python-setup by Pierre Haessig

📦 How to install modules in Python ?

- If you used Anaconda, use `conda install [name]` (in a terminal) to install module `[name]`:
- Or with the standard installer, use `pip install [name]`.

```
$ [sudo] pip/conda install keras  # example
```

🔍 How to find the module you need ?

- Ask your colleagues 😄 !
- Look on the Internet!
- Look directly on pypi.org (official) or anaconda.org

```
$ pip/conda search keras  # example
```

📦 Overview of main Python modules

> Standard library is very rich, but not for scientific applications

- **Numpy** (numpy.org) for `numpy.array` for multi-dim arrays and operations, and `numpy.linalg` module for linear algebra
- **Scipy** (scipy.org) for numerical computations (signal processing, integration, ODE integration, optimization etc)
- **Matplotlib** (matplotlib.org) for MATLAB-like 2D and 3D plots
- **pandas** for data manipulation (very powerful)
- **Scikit-Learn** (scikit-learn.org) for "classical" Machine Learning
- **Scikit-image** for 2D and generic image processing
- **Keras** (keras.io) for neural networks and deep learning

> And many others 📈 ! Check pypi.org

2. Main differences in syntax between Python and MATLAB

> Ref: mathesaurus.sourceforge.net/matlab-python-xref.pdf

	Python	MATLAB
File ext.	`.py`	`.m`
Comment	`# blabla...`	`% blabla...`
Indexing	`a[0]` to `a[-1]`	`a(1)` to `a(end)`
Slicing	`a[0:100]` (view)	`a(1:100)` (⚠ copy)
Operations	Element-wise by default	Linear algebra by default
Logic	Use `:` and indentation	Use `end` for closing

	Python	MATLAB
Help	`help(func)` (or `func?` IPython)	`help func`
And	`a and b`	`a && b`
Or	`a or b`	`a || b`
Datatype	`np.array` of *any* type	multi-dim `double` array
New array	`np.array([[1,2],[3,4]], dtype=float)`	`[1 2; 3 4]`
Size	`np.size(a)`	`size(a)`
Nb Dim	`np.ndim(a)`	`ndims(a)`
Last	`a[-1]`	`a(end)`

> With the usual shortcut `import numpy as np`

	Python	MATLAB
Tranpose	`a.T`	`a.'`
Conj. transpose	`a.conj().T` ⚠️	`a'`
Matrix ×	`a.dot(b)` or `a @ b`	`a * b`
Element-wise ×	`a * b`	`a .* b`
Element-wise /	`a / b`	`a ./ b`
Element-wise ^	`a ** 3`	`a .^ 3`
Zeros	`numpy.zeros((2,3,5))`	`zeros(2,3,5)`
Ones	`numpy.ones((2,3,5))`	`ones(2,3,5)`
Identity	`numpy.eye(10)`	`eye(10)`
Range for loops	`range(0, 100, 2)`	`1:2:100`
Range for arrays	`numpy.arange(0, 100, 2)`	`1:2:100`

	Python	MATLAB
Maximum	`np.max(a)`	`max(max(a))` ?
Random matrix	`np.random.rand(3,4)`	`rand(3,4)`
L^2 Norm	`np.sqrt(v @ v)` or `L.norm(v)`	`norm(v)`
Inverse	`L.inv(a)`	`inv(a)`
Pseudo inv	`L.pinv(a)`	`pinv(a)`
Solve syst.	`L.solve(a, b)`	`a \ b`
Eigen vals	`V, D = L.eig(a)`	`[V,D]=eig(a)`
FFT/IFFT	`np.fft(a)`, `np.ifft(a)`	`fft(a)`, `ifft(a)`

> With `import numpy as np; import numpy.linalg as L`

3. Examples of problems solved with Python

> Just to give some real examples of syntax and use of modules

1. 1D numerical integration and plot
2. Solving a 2^{nd} order Ordinary Differential Equation
3. Solving a constraint optimization problem and plotting solution
4. A simple neural network
5. Symbolic computations

3.1. 1D numerical integration and plot

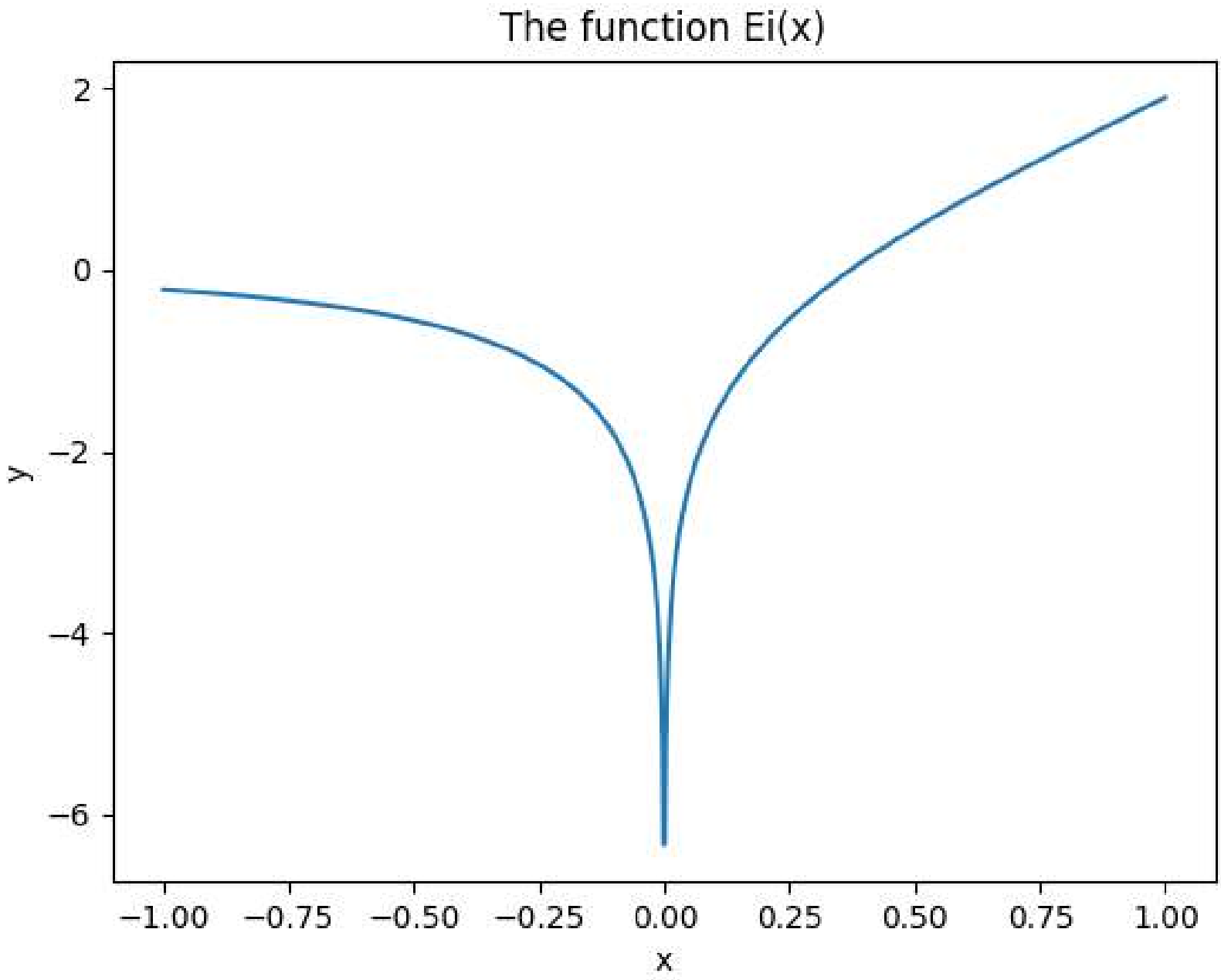
> Goal : evaluate and plot this function, on $[-1, 1]$:
>
> $$\mathrm{Ei}(x) := \int_{-\infty}^{x} \frac{\mathrm{e}^u}{u}\,\mathrm{d}u$$

How to?

Use modules!

- `numpy` for maths functions and arrays
- `scipy.integrate.quad` function for numerical integration
- `matplotlib.pyplot.plot` for 2D plotting

```
import numpy as np                      # standard convention
import matplotlib.pyplot as plt         # standard convention
from scipy.integrate import quad        # need only 1 function

def Ei(x, minfloat=1e-6, maxfloat=1000):
    def f(t):
        return np.exp(-t) / t
    if x > 0:
        return -1.0 * (quad(f, -x, -minfloat)[0]
                       + quad(f, minfloat, maxfloat)[0])
    else:
        return -1.0 * quad(f, -x, maxfloat)[0]


X = np.linspace(-1, 1, 1000) # 1000 points
Y = np.vectorize(Ei)(X)      # or [Ei(x) for x in X]
plt.plot(X, Y)               # MATLAB-like interface !
plt.title("The function Ei(x)")
plt.xlabel("x"); plt.ylabel("y")
plt.savefig("figures/Ei_integral.png")
plt.show()
```


The function Ei(x)
2
0
−2
−4
−6
y
−1.00
−0.75
−0.50
−0.25
0.00
0.25
0.50
0.75
1.00
x

3.2. Solving a 2^{nd} order ODE

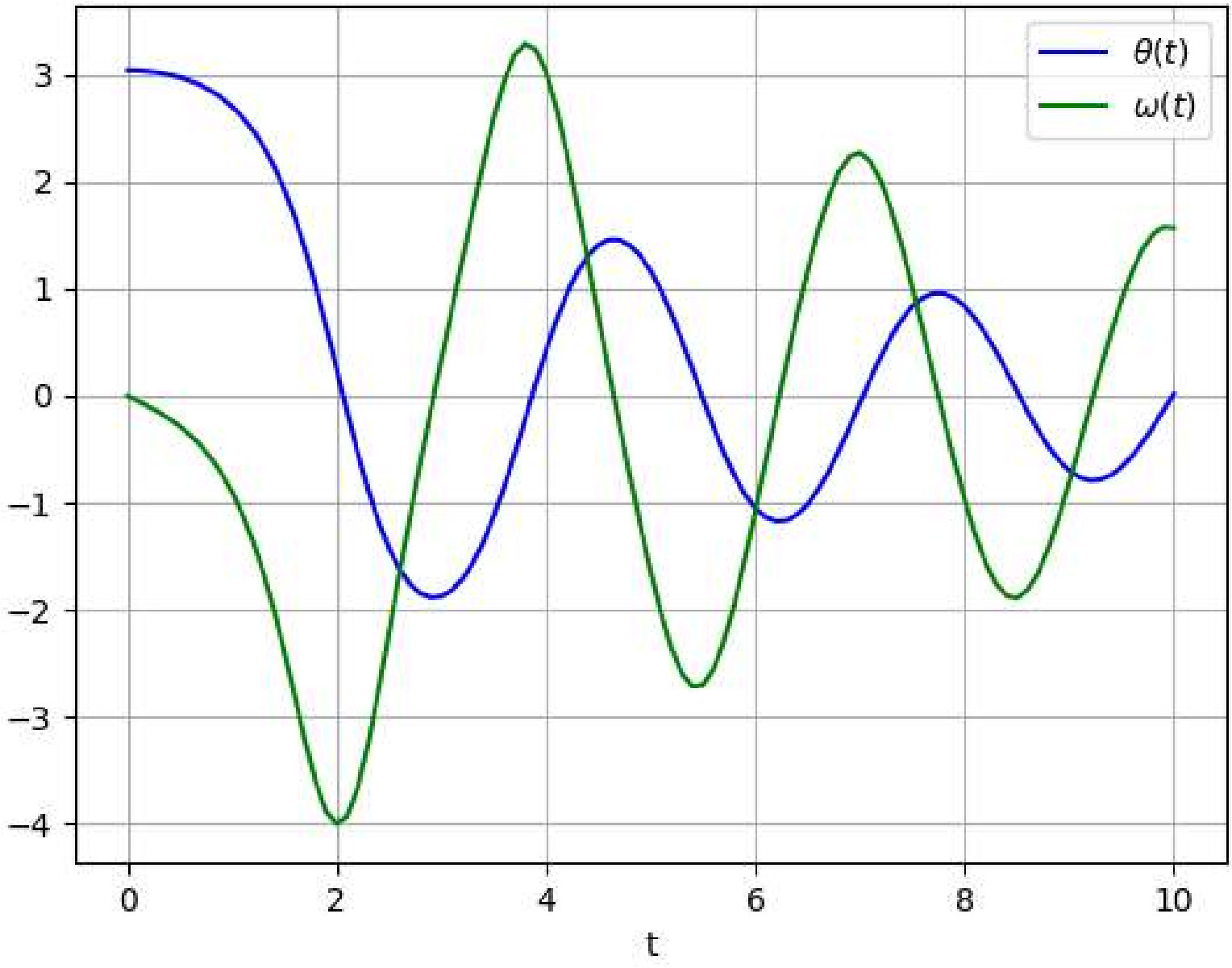
> Goal : solve and plot the differential equation of a pendulum:
>
> $$\theta''(t) + b\,\theta'(t) + c\,\sin(\theta(t)) = 0$$
>
> For $b = 1/4, c = 5, \theta(0) = \pi - 0.1, \theta'(0) = 0, t \in [0, 10]$

How to?

Use modules!

- `scipy.integrate.odeint` function for ODE integration
- `matplotlib.pyplot.plot` for 2D plotting

```
import numpy as np
import matplotlib.pyplot as plt
from scipy.integrate import odeint   # use Runge-Kutta 4

def pend(y, t, b, c):  # function definition
    return np.array([y[1], -b*y[1] - c*np.sin(y[0])])

b, c = 0.25, 5.0  # tuple assignment
y0 = np.array([np.pi - 0.1, 0.0])
t = np.linspace(0, 10, 101)  # on [0,10] with 101 points

sol = odeint(pend, y0, t, args=(b, c))

plt.plot(t, sol[:, 0], 'b', label=r'$\theta(t)$')# blue
plt.plot(t, sol[:, 1], 'g', label=r'$\omega(t)$')# green
plt.legend(loc='best')
plt.xlabel('t')
plt.grid()
plt.savefig("figures/Pendulum_solution.png")
plt.show()
```


θ(t)
ω(t)
3
2
1
0
−1
−2
−3
−4
0
2
4
6
8
10
t

3.3. Constraint optimization problem

> Goal: minimize a function under linear inequality constraints:
>
> $$f(x, y) := (x - 1)^2 + (y - 2.5)^2$$
>
> $$\text{such that } \begin{cases} x \geq 0 \text{ and } y \geq 0 \\ x - 2y + 2 \geq 0 \\ -x - 2y + 6 \geq 0 \\ x + 2y + 2 \geq 0 \end{cases}$$

How to?

- `scipy.optimize.minimize` function for black-box minimization

3.3. Constraint optimization problem

```
from scipy.optimize import minimize

def obj(x):
    return (x[0] - 1)**2 + (x[1] - 2.5)**2

x0 = (2, 0)  # first guess

bnds = ((0, None), (0, None))  # [0, +oo) for x and y

cons = ({'type': 'ineq', 'fun': lambda x: x[0]-2*x[1]+2},
        {'type': 'ineq', 'fun': lambda x:-x[0]-2*x[1]+6},
        {'type': 'ineq', 'fun': lambda x:-x[0]+2*x[1]+2})


res = minimize(obj, x0, method='SLSQP', bounds=bnds,
               constraints=cons)
print("Minimum is", res.x)  # Minimum is (1.4, 1.7)
```

3.4. A simple 2-layer neural network

> Using keras (keras.io) it's very simple and concise 😎 !

```
from keras.models import Sequential
model = Sequential()

from keras.layers import Dense
model.add(Dense(units=64, activation='relu', input_dim=100))
model.add(Dense(units=10, activation='softmax'))

model.compile(loss='categorical_crossentropy',
              optimizer='sgd', metrics=['accuracy'])

# x_train and y_train: numpy arrays like in Scikit-Learn
model.fit(x_train, y_train, epochs=5, batch_size=32)

# evaluate or predict using the model
loss_and_metrics = model.evaluate(x_test, y_test, batch_size=12
classes = model.predict(x_test, batch_size=128)
```

3.5. Symbolic computations

- MATLAB has the Symbolic Math Toolbox (for 400€/year)…
- Python has the **SymPy** module (sympy.org)
- Ex: Powerful webapp : sympygamma.com (like Wolfram|Alpha)
- ✨ Lots of Python code written for numerical values can work directly for symbolic values!

a. A few basic examples

b. A second example from my latest research article…

- the same code works for numbers, or exact fractions
- or symbols $\mu_1, \dots, \mu_K$!

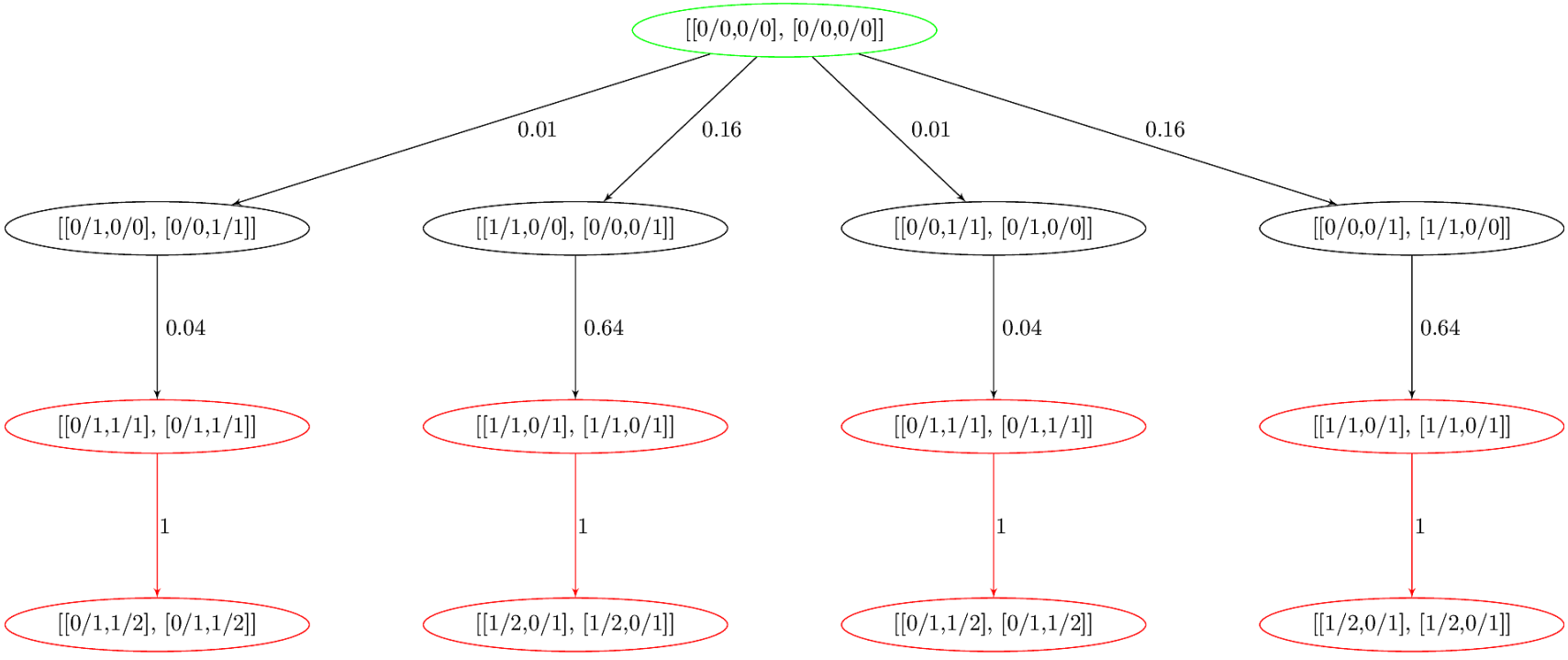
3.5.a. A few basic examples

> Using sympy (sympy.org)

```
from sympy import *      # usually a bad habit
x, t, z, nu = symbols('x t z nu')

diff(sin(x)*exp(x), x)  # exp(x)*sin(x) + exp(x)*cos(x)

integrate(exp(x)*sin(x) + exp(x)*cos(x), x)  # exp(x)*sin(x)

integrate(sin(x**2), (x, -oo, oo))  # sqrt(2)*sqrt(pi)/2

limit(sin(x)/x, x, 0)   # 1

y = Function('y')
dsolve(Eq(y(t).diff(t, t) - y(t), exp(t)), y(t))
# Eq(y(t), C2*exp(-t) + (C1 + t/2)*exp(t))
```

> See docs.sympy.org for more examples

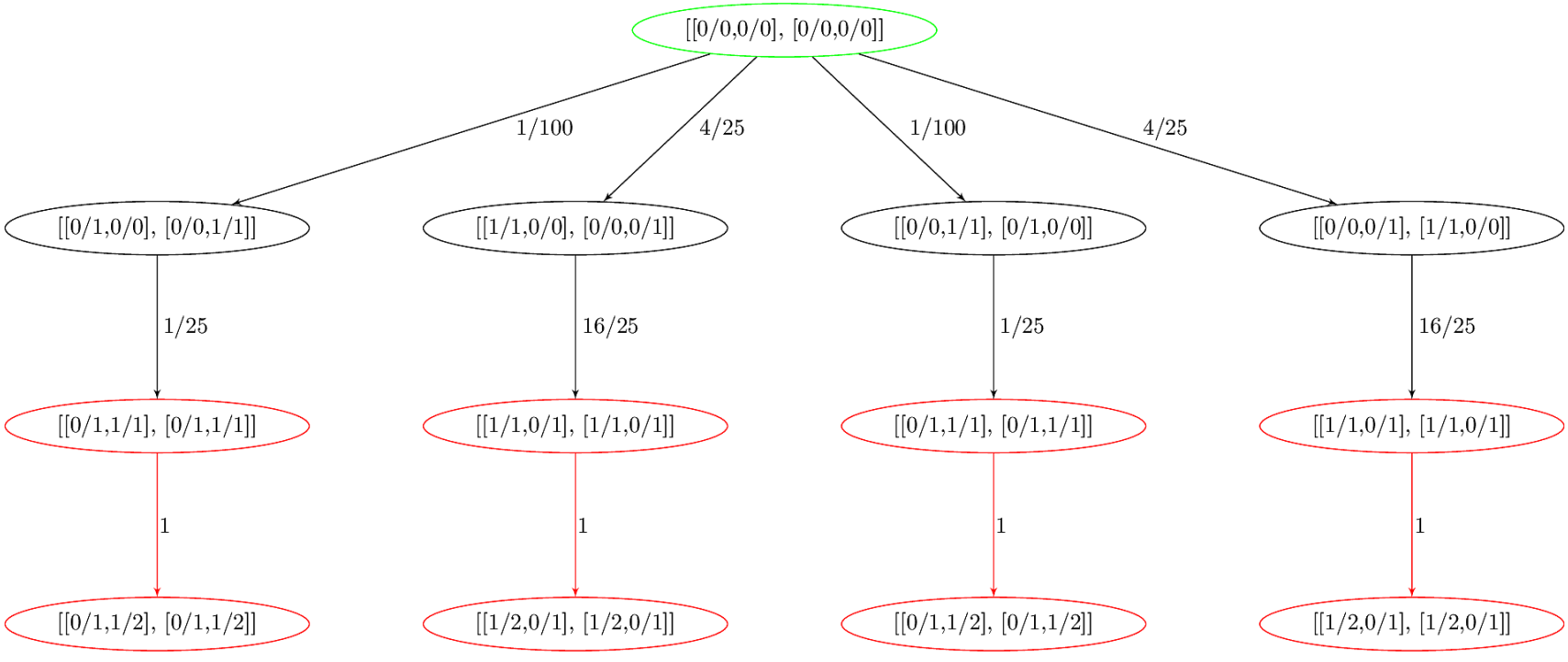
3.5.b. Example : generated graph with numbers



Tree exploration for K=2 arms and M=2 players using Selfish UCB, for depth=3 : 68 leafs, 2 absorbing

> Graph saved a DOT file and to a TikZ graph with dot2tex

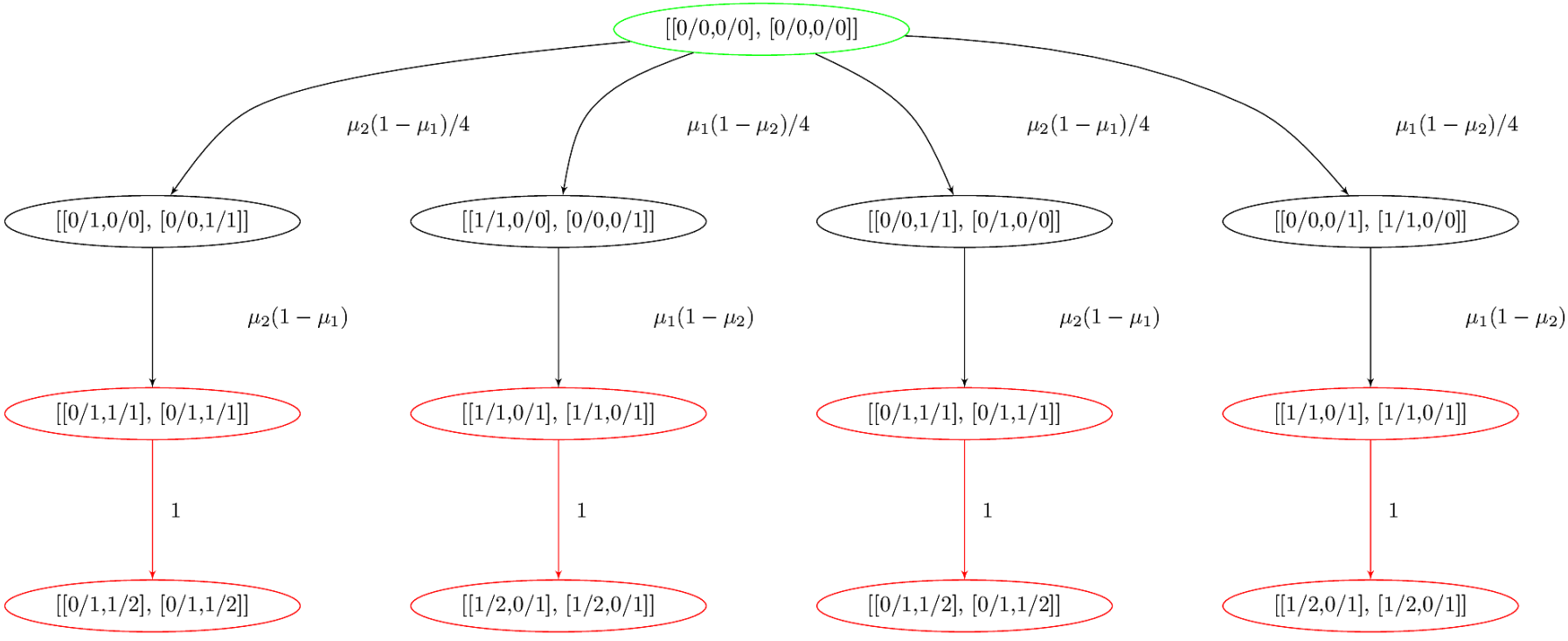
3.5.b. Example : generated graph with fractions



Tree exploration for K=2 arms and M=2 players using Selfish UCB, for depth=3 : 68 leafs, 2 absorbing

> Source: banditslilian.gforge.inria.fr/docs/complete_tree_exploration_for_MP_bandits.html

3.5.b. Example : generated graph with symbols



Tree exploration for K=2 arms and M=2 players using Selfish UCB, for depth=3 : 68 leafs, 2 absorbing

Conclusion (1/3)

Sum-up

- I hope you got a good introduction to Python 👌
  - Good tutorials: www.scipy-lectures.org
- It's not hard to migrate ✈️ from MATLAB to Python
- More ressources 🔳 :
  - official documentation: docs.scipy.org/doc/numpy-dev/user/numpy-for-matlab-users.html
  - a good 45-minute training video : youtu.be/YkCegjtoHFQ
  - mathesaurus.sourceforge.net/matlab-numpy.html and mathesaurus.sourceforge.net/matlab-python-xref.pdf

Conclusion (2/3)

Next GouTP @ SCEE

> By Lilian Besson 👋

- **Jupyter notebooks** for teaching and research
  ↪ see jupyter.org if you are curious

GouTP @ FAST or AUT ?

> By Pierre Haessig ?

- **Julia programming language** (~ between Python and Matlab)
  ↪ see julialang.org if you are curious

> 👉 By *you*? Any idea is welcome! 😀

Conclusion (3/3)

> *Thanks for joining 👏 !*
>
> *Contact us if you want to do a GouTP !*

Your mission, if you accept it… 💥

1. *Padawan level :* Train yourself a little bit on Python 🐍
   ↪ python.org or introtopython.org or learnpython.org
2. *Jedi level :* Try to solve a numerical system, from your research or teaching, in Python instead of MATLAB
3. *Master level :* From now on, try to use (only?) open-source tools for your research (Python and others)