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# **pyPESTO Documentation**

***Release 0.0.11***

**The pyPESTO developers**

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Version: 0.0.11

Source code: <https://github.com/icb-dcm/pypesto>



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## Install and upgrade

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### 1.1 Requirements

This package requires Python 3.6 or later. It is tested on Linux using Travis continuous integration.

#### 1.1.1 I cannot use my system's Python distribution, what now?

Several Python distributions can co-exist on a single system. If you don't have access to a recent Python version via your system's package manager (this might be the case for old operating systems), it is recommended to install the latest version of the [Anaconda Python 3 distribution](#).

Also, there is the possibility to use multiple virtual environments via:

```
python3 -m virtualenv ENV_NAME
source ENV_NAME/bin/activate
```

where ENV\_NAME denotes an individual environment name, if you do not want to mess up the system environment.

### 1.2 Install from PIP

The package can be installed from the Python Package Index PyPI via pip:

```
pip3 install pypesto
```

### 1.3 Install from GIT

If you want the bleeding edge version, install directly from github:

```
pip3 install git+https://github.com/icb-dcm/pypesto.git
```

If you need to have access to the source code, you can download it via:

```
git clone https://github.com/icb-dcm/pypesto.git
```

and then install from the local repository via:

```
cd pypesto
pip3 install .
```

## 1.4 Upgrade

If you want to upgrade from an existing previous version, replace `install` by `install --upgrade` in the above commands.

## 1.5 Install optional packages

- This package includes multiple comfort methods simplifying its use for parameter estimation for models generated using the toolbox [amici](#). To use AMICI, install it via pip:

```
pip3 install amici
```

- This package inherently supports optimization using the dlib toolbox. To use it, install dlib via:

```
pip3 install dlib
```



The following examples cover typical use cases and should help get a better idea of how to use this package:

### 2.1 Rosenbrock banana

Here, we perform optimization for the Rosenbrock banana function, which does not require an AMICI model. In particular, we try several ways of specifying derivative information.

```
[1]: import pypesto
import numpy as np
import scipy as sp
import matplotlib.pyplot as plt
from mpl_toolkits.mplot3d import Axes3D

%matplotlib inline
```

#### 2.1.1 Define the objective and problem

```
[2]: # first type of objective
# get the optimizer trace
objective_options = pypesto.ObjectiveOptions(trace_record=True,
                                              trace_all=False,
                                              trace_save_iter=1)

objective1 = pypesto.Objective(fun=sp.optimize.rosen,
                              grad=sp.optimize.rosen_der,
                              hess=sp.optimize.rosen_hess,
                              options=objective_options)

# second type of objective
def rosen2(x):
    return sp.optimize.rosen(x), sp.optimize.rosen_der(x), sp.optimize.rosen_hess(x)
```

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```
objective2 = pypesto.Objective(fun=rosen2, grad=True, hess=True)

dim_full = 10
lb = -5 * np.ones((dim_full, 1))
ub = 5 * np.ones((dim_full, 1))

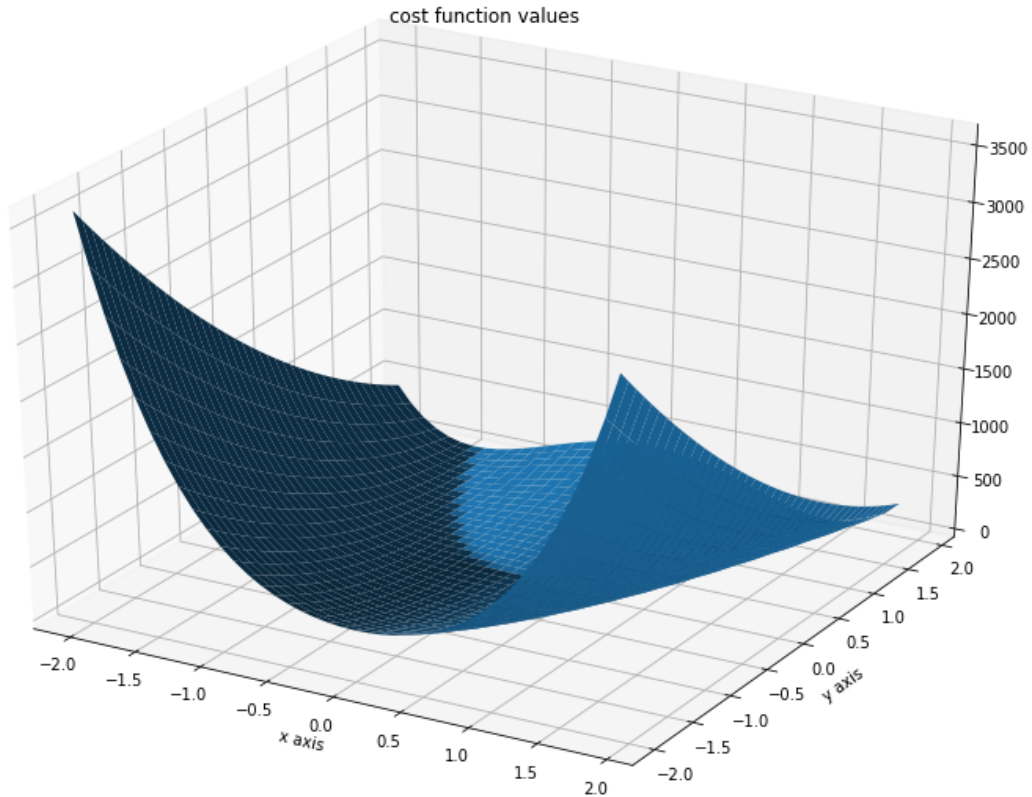
problem1 = pypesto.Problem(objective=objective1, lb=lb, ub=ub)
problem2 = pypesto.Problem(objective=objective2, lb=lb, ub=ub)
```

## 2.1.2 Illustration

```
[3]: x = np.arange(-2, 2, 0.1)
     y = np.arange(-2, 2, 0.1)
     x, y = np.meshgrid(x, y)
     z = np.zeros_like(x)
     for j in range(0, x.shape[0]):
         for k in range(0, x.shape[1]):
             z[j,k] = objective1([x[j,k], y[j,k]], (0,))
```

```
[4]: fig = plt.figure()
     fig.set_size_inches(*(14,10))
     ax = plt.axes(projection='3d')
     ax.plot_surface(X=x, Y=y, Z=z)
     plt.xlabel('x axis')
     plt.ylabel('y axis')
     ax.set_title('cost function values')
```

```
[4]: Text(0.5, 0.92, 'cost function values')
```



### 2.1.3 Run optimization

```
[5]: # create different optimizers
optimizer_bfgs = pypesto.ScipyOptimizer(method='l-bfgs-b')
optimizer_tnc = pypesto.ScipyOptimizer(method='TNC')
optimizer_dogleg = pypesto.ScipyOptimizer(method='dogleg')

# set number of starts
n_starts = 20

# Run optimizations for different optimizers
result1_bfgs = pypesto.minimize(problem=problem1, optimizer=optimizer_bfgs, n_
    ↪starts=n_starts)
result1_tnc = pypesto.minimize(problem=problem1, optimizer=optimizer_tnc, n_starts=n_
    ↪starts)
result1_dogleg = pypesto.minimize(problem=problem1, optimizer=optimizer_dogleg, n_
    ↪starts=n_starts)

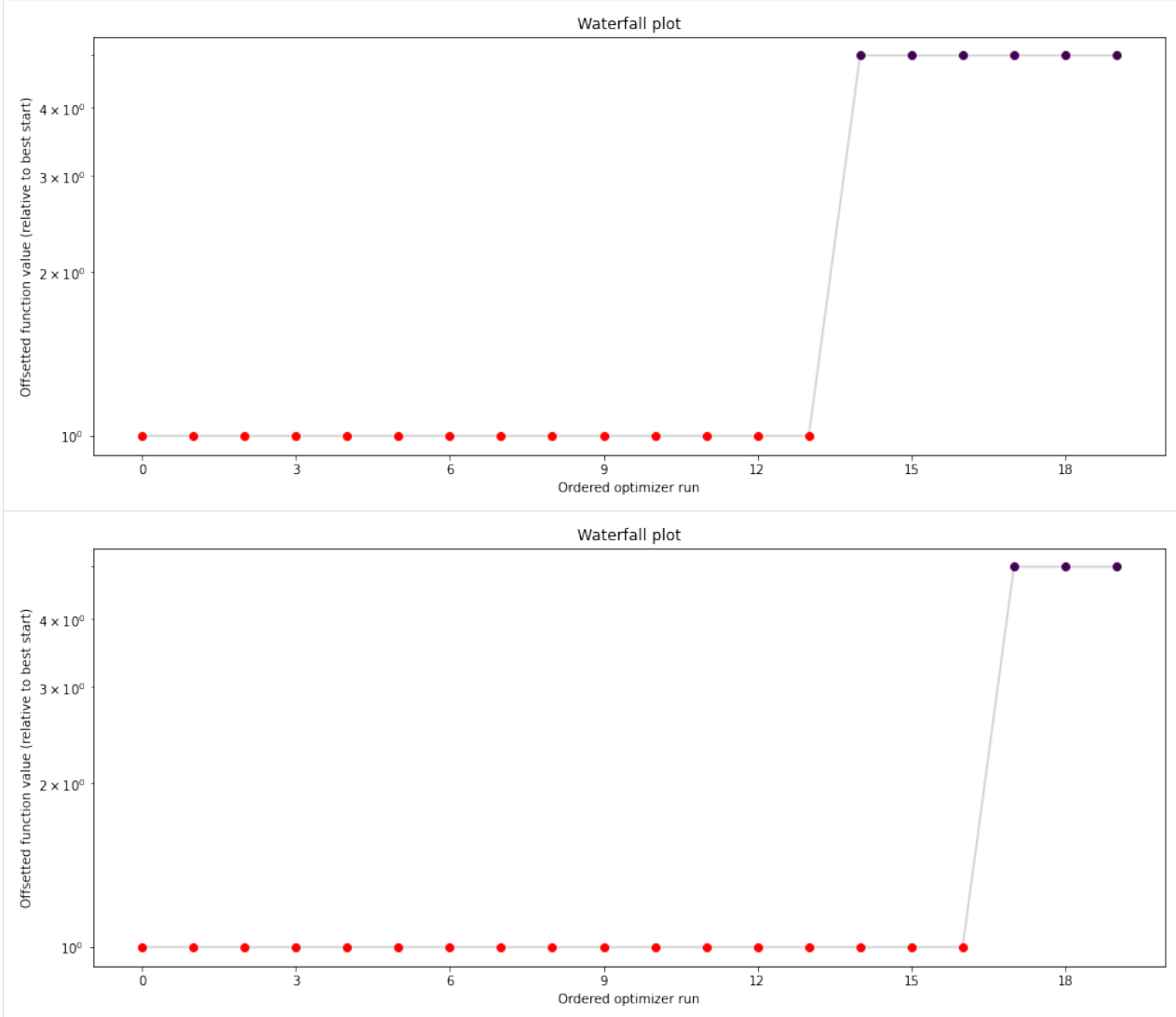
# Optimize second type of objective
result2 = pypesto.minimize(problem=problem2, optimizer=optimizer_tnc, n_starts=n_
    ↪starts)
```

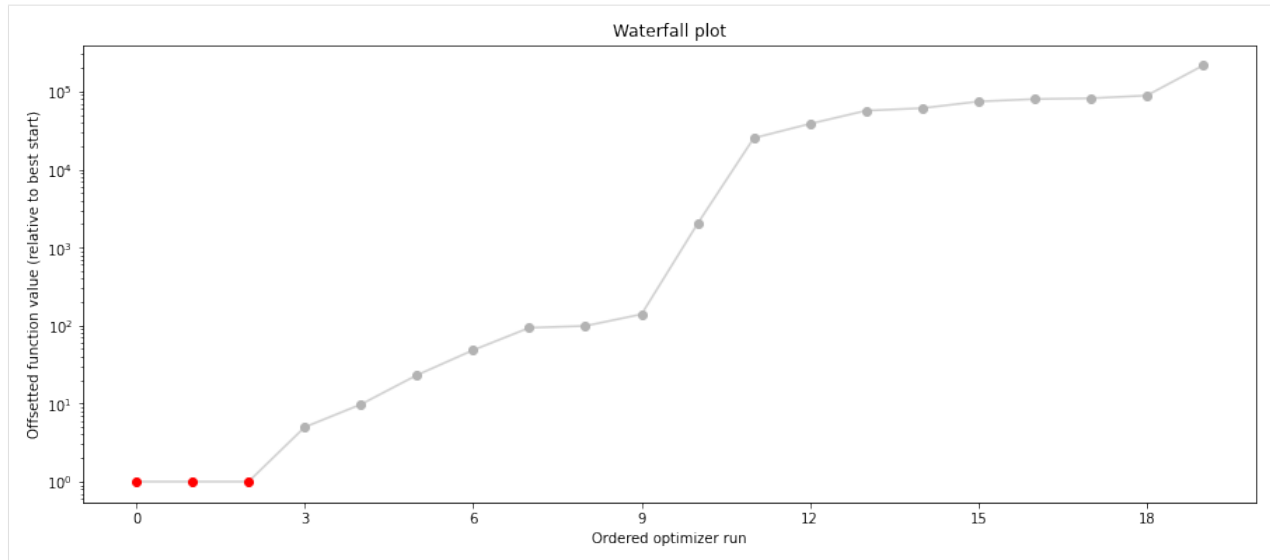
## 2.1.4 Visualize and compare optimization results

```
[6]: import pypesto.visualize

# plot separated waterfalls
pypesto.visualize.waterfall(result1_bfgs, size=(15,6))
pypesto.visualize.waterfall(result1_tnc, size=(15,6))
pypesto.visualize.waterfall(result1_dogleg, size=(15,6))

[6]: <matplotlib.axes._subplots.AxesSubplot at 0x132d1ec10>
```

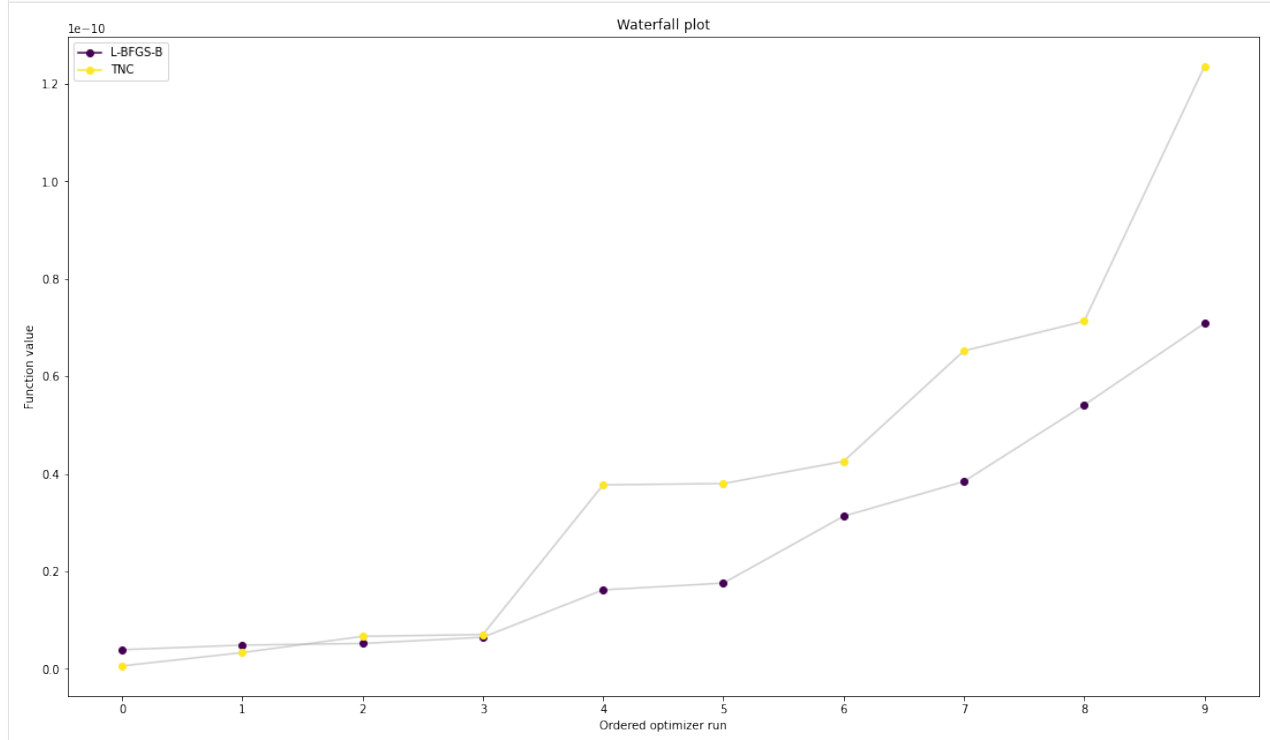




We can now have a closer look, which method performed better: Let's first compare bfgs and TNC, since both methods gave good results. How does they fine convergence look like?

```
[7]: # plot one list of waterfalls
pypesto.visualize.waterfall([result1_bfgs, result1_tnc],
                             legends=['L-BFGS-B', 'TNC'],
                             start_indices=10,
                             scale_y='lin')
```

```
[7]: <matplotlib.axes._subplots.AxesSubplot at 0x135795e10>
```



```
[8]: # retrieve second optimum
```

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```

all_x = result1_bfgs.optimize_result.get_for_key('x')
all_fval = result1_bfgs.optimize_result.get_for_key('fval')
x = all_x[19]
fval = all_fval[19]
print('Second optimum at: ' + str(fval))

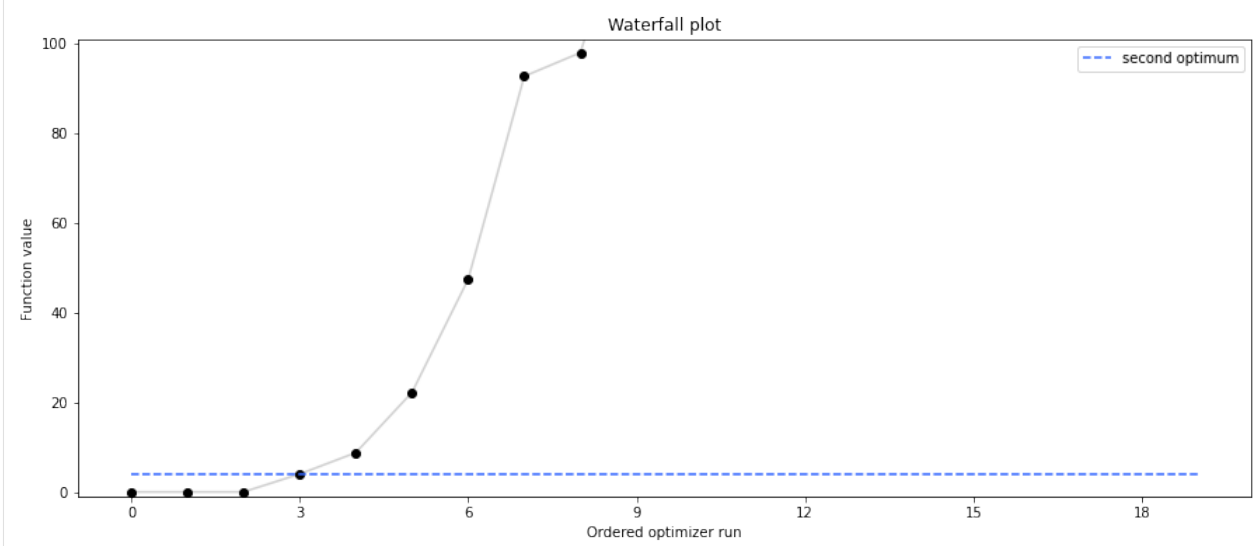
# create a reference point from it
ref = {'x': x, 'fval': fval, 'color': [
    0.2, 0.4, 1., 1.], 'legend': 'second optimum'}
ref = pypesto.visualize.create_references(ref)

# new waterfall plot with reference point for second optimum
pypesto.visualize.waterfall(result1_dogleg, size=(15,6),
                           scale_y='lin', y_limits=[-1, 101],
                           reference=ref, colors=[0., 0., 0., 1.])

```

Second optimum at: 3.986579113637416

[8]: <matplotlib.axes.\_subplots.AxesSubplot at 0x135d87450>



## 2.1.5 Visualize parameters

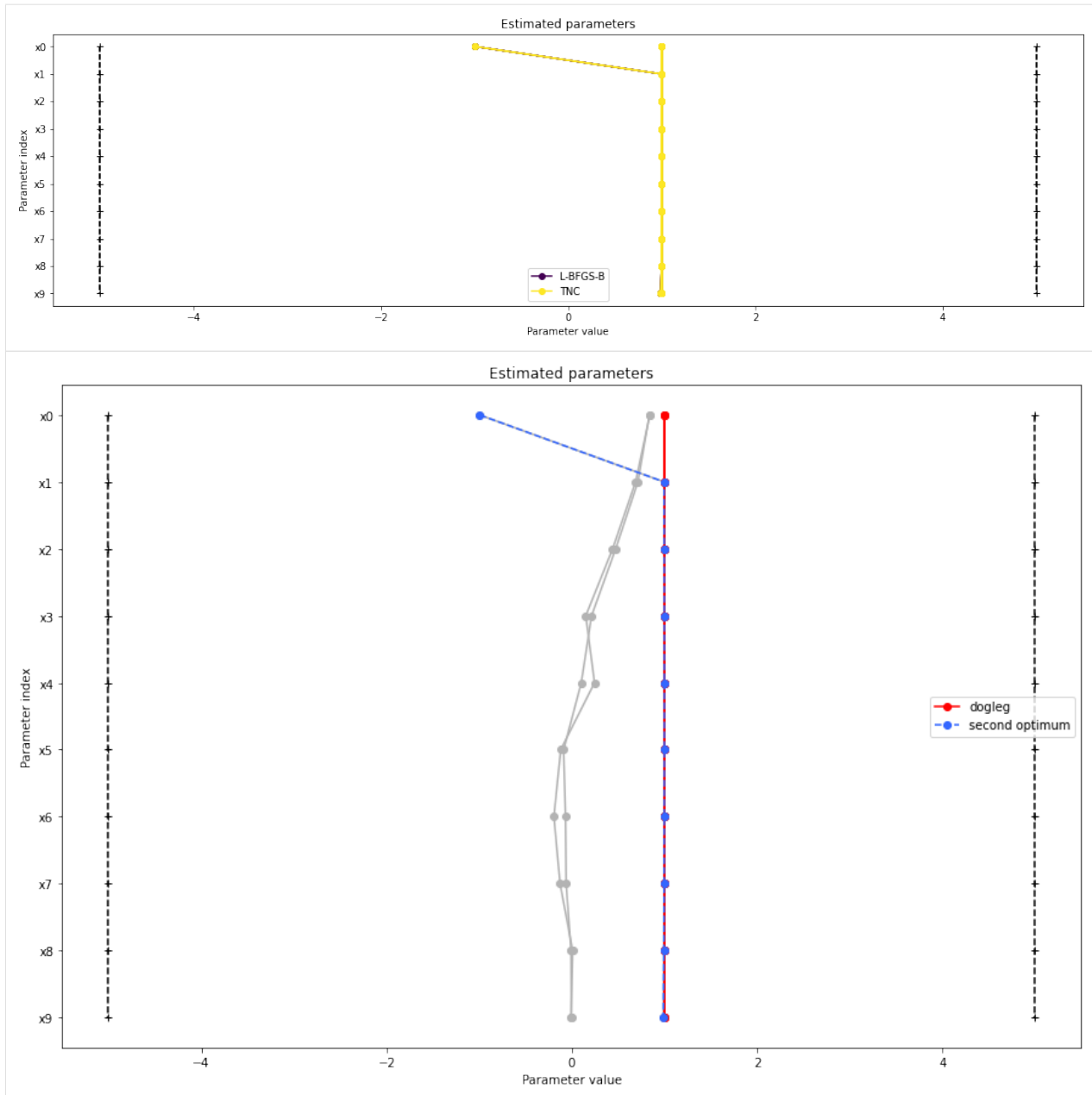
There seems to be a second local optimum. We want to see whether it was also found by the dogleg method

```

[9]: pypesto.visualize.parameters([result1_bfgs, result1_tnc],
                                legends=['L-BFGS-B', 'TNC'],
                                balance_alpha=False)
pypesto.visualize.parameters(result1_dogleg,
                              legends='dogleg',
                              reference=ref,
                              size=(15,10),
                              start_indices=[0, 1, 2, 3, 4, 5],
                              balance_alpha=False)

```

[9]: <matplotlib.axes.\_subplots.AxesSubplot at 0x136971bd0>



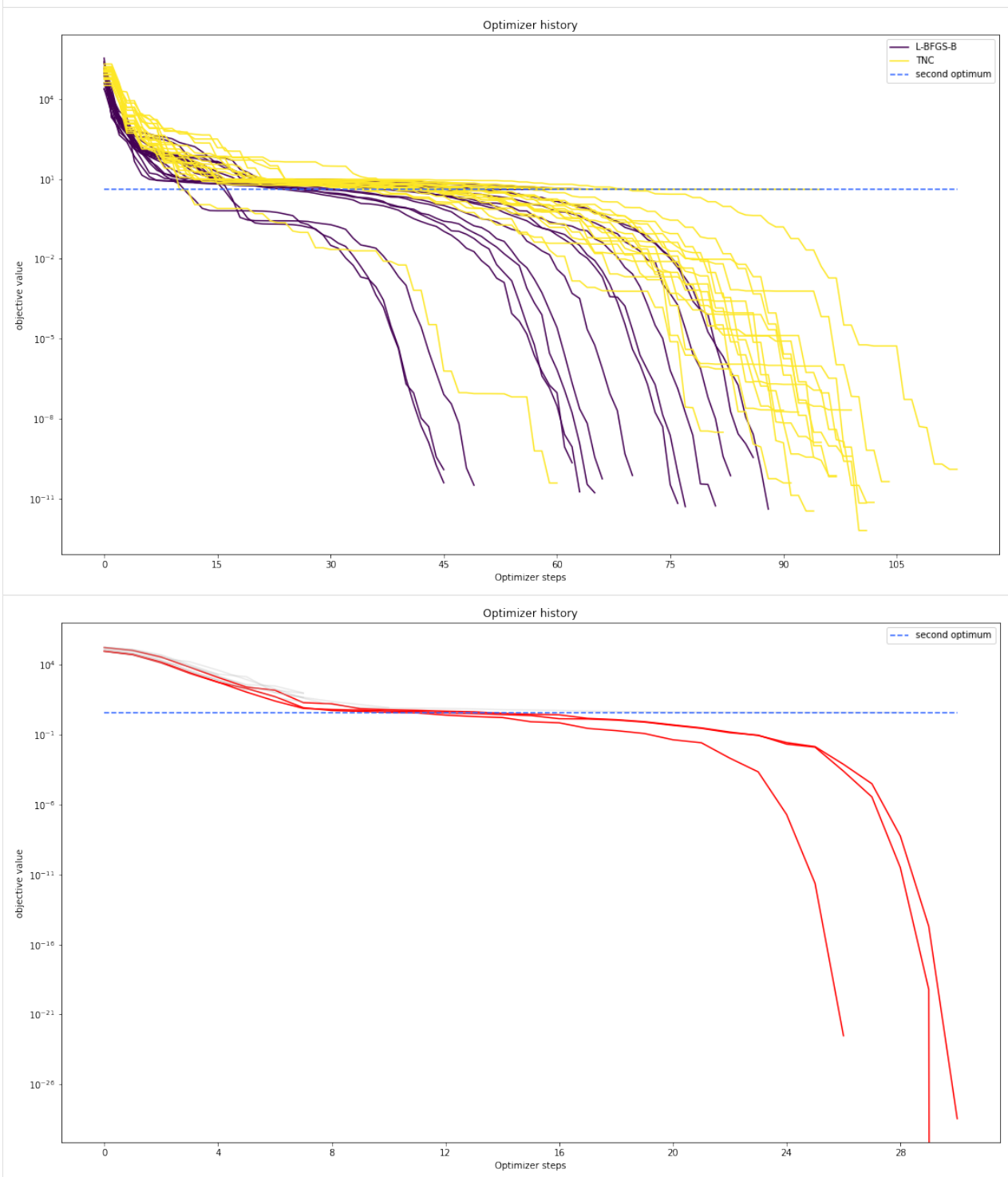
## 2.1.6 Optimizer history

Let's compare optimizer progress over time.

```
[10]: # plot one list of waterfalls
pypesto.visualize.optimizer_history([result1_bfgs, result1_tnc],
                                   legends=['L-BFGS-B', 'TNC'],
                                   reference=ref)

# plot one list of waterfalls
pypesto.visualize.optimizer_history(result1_dogleg,
                                   reference=ref)
```

```
[10]: <matplotlib.axes._subplots.AxesSubplot at 0x136924050>
```



We can also visualize this using other scalings or offsets...

```
[11]: # plot one list of waterfalls
pypesto.visualize.optimizer_history([result1_bfgs, result1_tnc],
                                   legends=['L-BFGS-B', 'TNC'],
```

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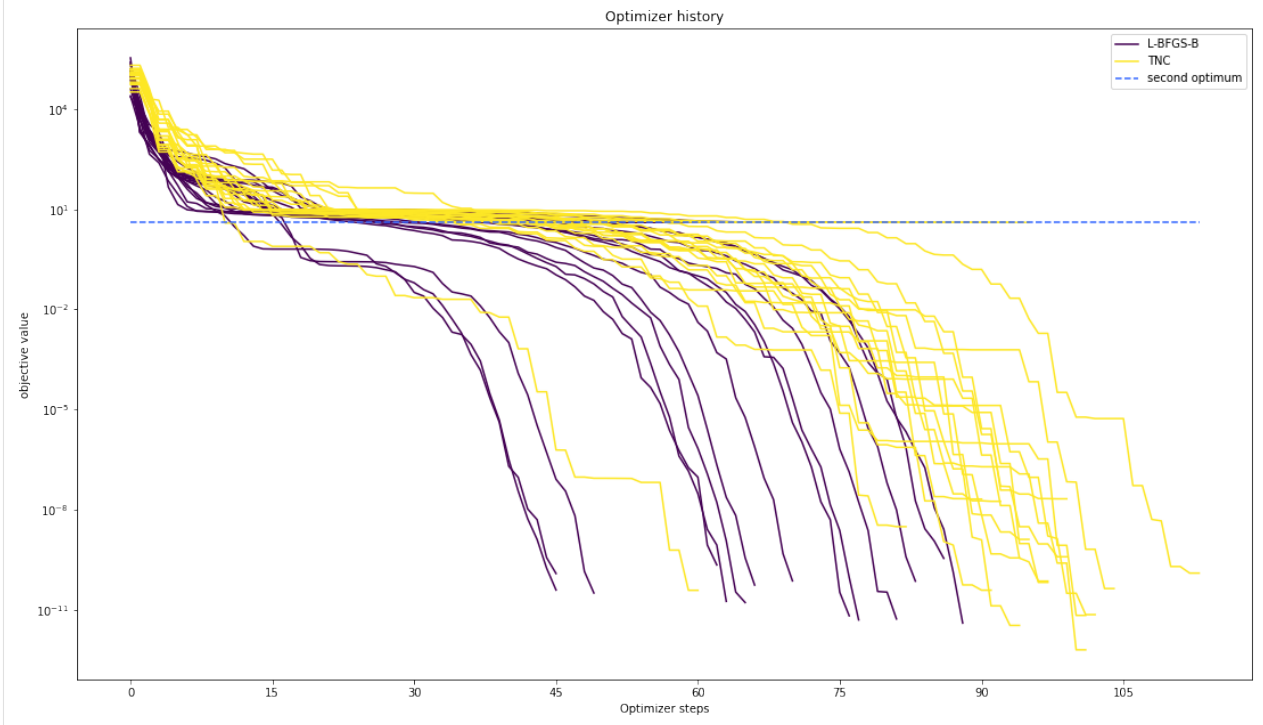
```

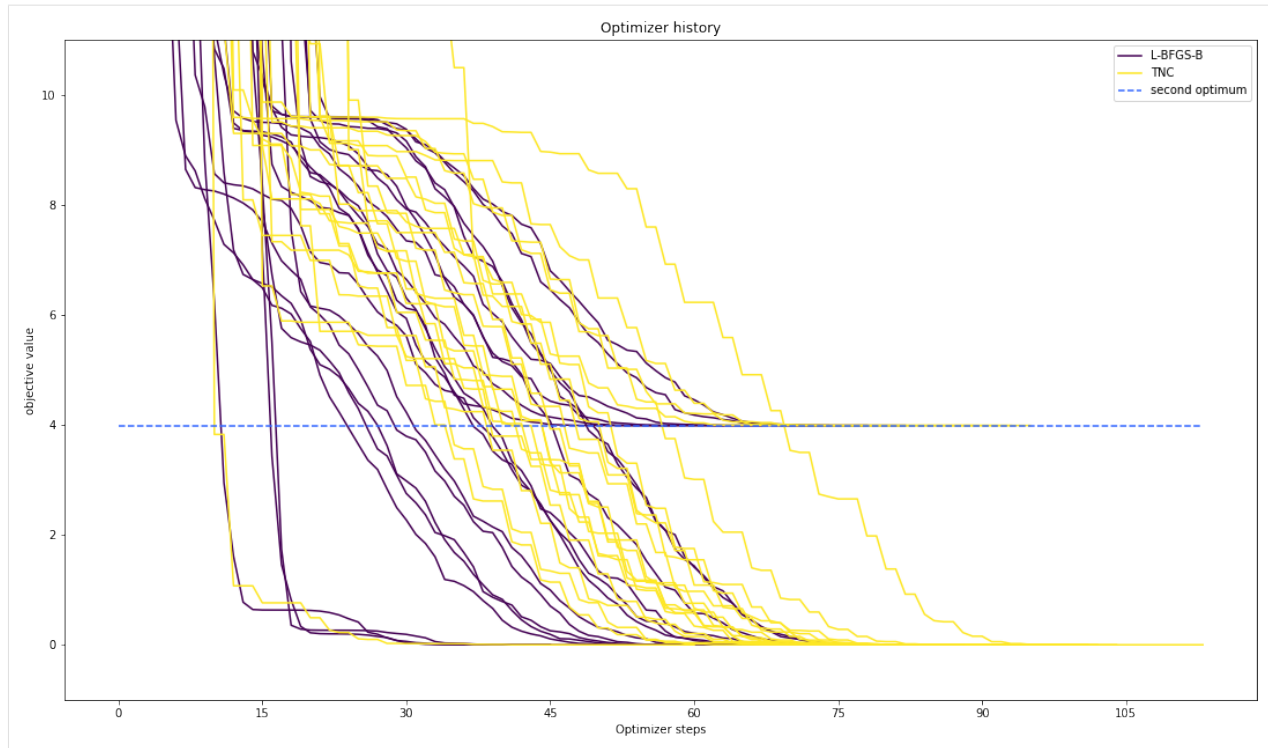
reference=ref,
offset_y=0.)

# plot one list of waterfalls
pypesto.visualize.optimizer_history([result1_bfgs, result1_tnc],
                                   legends=['L-BFGS-B', 'TNC'],
                                   reference=ref,
                                   scale_y='lin',
                                   y_limits=[-1., 11.])

```

```
[11]: <matplotlib.axes._subplots.AxesSubplot at 0x132cf5c50>
```





## 2.1.7 Compute profiles

The profiling routine needs a problem, a results object and an optimizer.

Moreover it accepts an index of integer (`profile_index`), whether or not a profile should be computed.

Finally, an integer (`result_index`) can be passed, in order to specify the local optimum, from which profiling should be started.

```
[12]: # compute profiles
profile_options = pypesto.ProfileOptions(min_step_size=0.0005,
    delta_ratio_max=0.05,
    default_step_size=0.005,
    ratio_min=0.03)

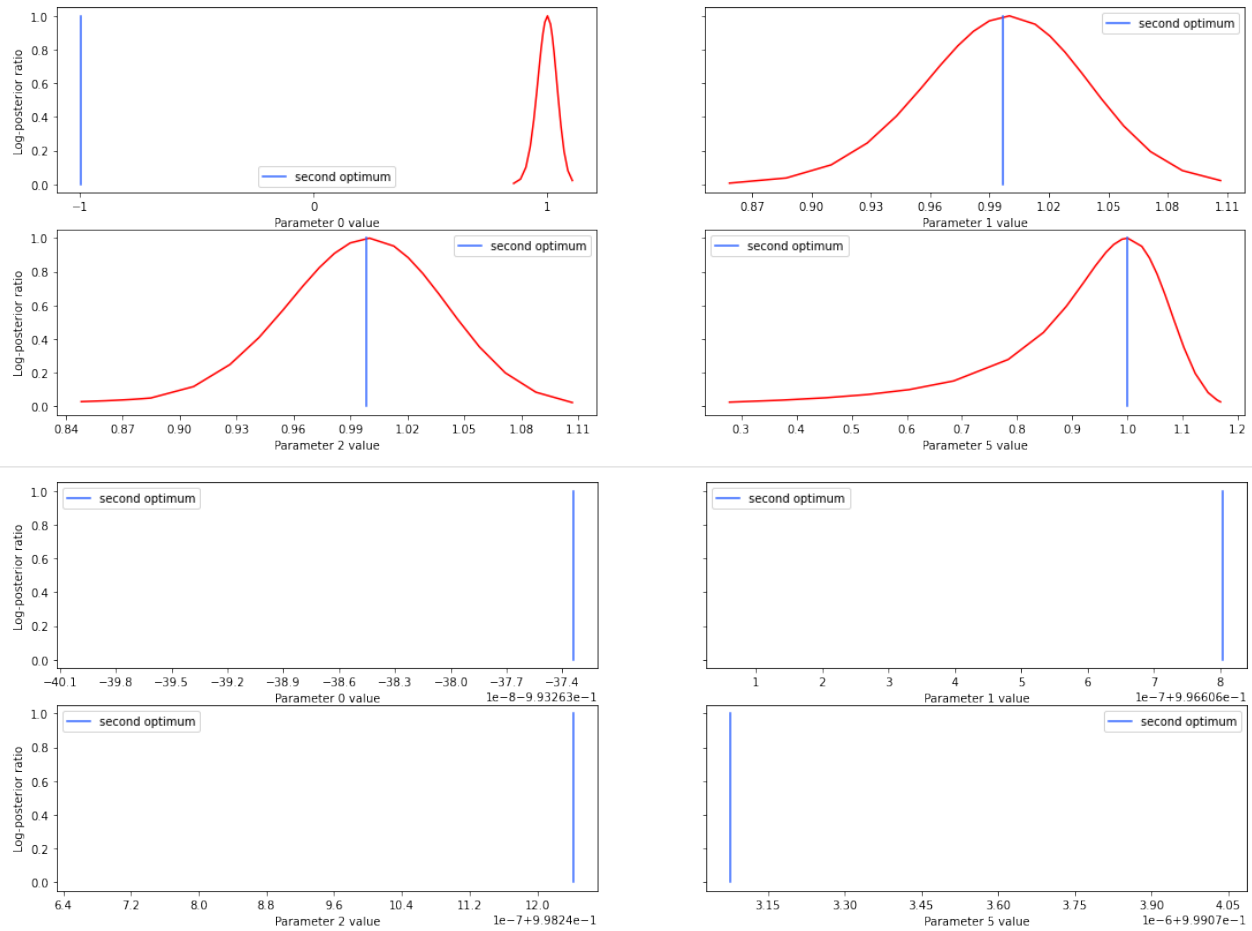
result1_tnc = pypesto.parameter_profile(
    problem=problem1,
    result=result1_tnc,
    optimizer=optimizer_tnc,
    profile_index=np.array([1, 1, 1, 0, 0, 1, 0, 1, 0, 0, 0]),
    result_index=0,
    profile_options=profile_options)

# compute profiles from second optimum
result1_tnc = pypesto.parameter_profile(
    problem=problem1,
    result=result1_tnc,
    optimizer=optimizer_tnc,
    profile_index=np.array([1, 1, 1, 0, 0, 1, 0, 1, 0, 0, 0]),
    result_index=19,
    profile_options=profile_options)
```

## 2.1.8 Visualize and analyze results

pypesto offers easy-to-use visualization routines:

```
[13]: # specify the parameters, for which profiles should be computed
ax = pypesto.visualize.profiles(result1_tnc, profile_indices = [0,1,2,5],
                                reference=ref, profile_list_id=0)
# plot profiles again, now from second optimum
ax = pypesto.visualize.profiles(result1_tnc, profile_indices = [0,1,2,5],
                                reference=ref, profile_list_id=1)
```



If the result needs to be examined in more detail, it can easily be exported as a pandas.DataFrame:

```
[14]: result1_tnc.optimize_result.as_dataframe(['fval', 'n_fval', 'n_grad',
                                                'n_hess', 'n_res', 'n_sres', 'time'])
```

```
[14]:
```

|   | fval         | n_fval | n_grad | n_hess | n_res | n_sres | time     |
|---|--------------|--------|--------|--------|-------|--------|----------|
| 0 | 6.209909e-13 | 182    | 182    | 0      | 0     | 0      | 3.018615 |
| 1 | 3.347752e-12 | 201    | 201    | 0      | 0     | 0      | 3.129823 |
| 2 | 6.678543e-12 | 199    | 199    | 0      | 0     | 0      | 3.283912 |
| 3 | 7.053040e-12 | 220    | 220    | 0      | 0     | 0      | 4.203216 |
| 4 | 3.774925e-11 | 108    | 108    | 0      | 0     | 0      | 1.765140 |
| 5 | 3.801535e-11 | 189    | 189    | 0      | 0     | 0      | 4.939764 |
| 6 | 4.257708e-11 | 215    | 215    | 0      | 0     | 0      | 3.341858 |
| 7 | 6.523019e-11 | 184    | 184    | 0      | 0     | 0      | 2.943149 |
| 8 | 7.130051e-11 | 183    | 183    | 0      | 0     | 0      | 4.247466 |

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|    |              |     |     |   |   |   |          |
|----|--------------|-----|-----|---|---|---|----------|
| 9  | 1.235387e-10 | 216 | 216 | 0 | 0 | 0 | 3.459202 |
| 10 | 3.527061e-10 | 195 | 195 | 0 | 0 | 0 | 3.148446 |
| 11 | 3.810705e-10 | 211 | 211 | 0 | 0 | 0 | 3.243232 |
| 12 | 1.265625e-09 | 189 | 189 | 0 | 0 | 0 | 3.081982 |
| 13 | 3.046493e-09 | 165 | 165 | 0 | 0 | 0 | 2.597345 |
| 14 | 1.748569e-08 | 186 | 186 | 0 | 0 | 0 | 2.902532 |
| 15 | 2.042323e-08 | 159 | 159 | 0 | 0 | 0 | 2.793006 |
| 16 | 2.076666e-08 | 205 | 205 | 0 | 0 | 0 | 3.255512 |
| 17 | 3.986579e+00 | 173 | 173 | 0 | 0 | 0 | 2.814030 |
| 18 | 3.986579e+00 | 172 | 172 | 0 | 0 | 0 | 2.740488 |
| 19 | 3.986579e+00 | 199 | 199 | 0 | 0 | 0 | 3.038311 |

## 2.2 Conversion reaction

```
[1]: import importlib
import os
import sys
import numpy as np
import amici
import amici.plotting
import pypesto

# sbml file we want to import
sbml_file = 'conversion_reaction/model_conversion_reaction.xml'
# name of the model that will also be the name of the python module
model_name = 'model_conversion_reaction'
# directory to which the generated model code is written
model_output_dir = 'tmp/' + model_name
```

### 2.2.1 Compile AMICI model

```
[2]: # import sbml model, compile and generate amici module
sbml_importer = amici.SbmlImporter(sbml_file)
sbml_importer.sbml2amici(model_name,
                        model_output_dir,
                        verbose=False)
```

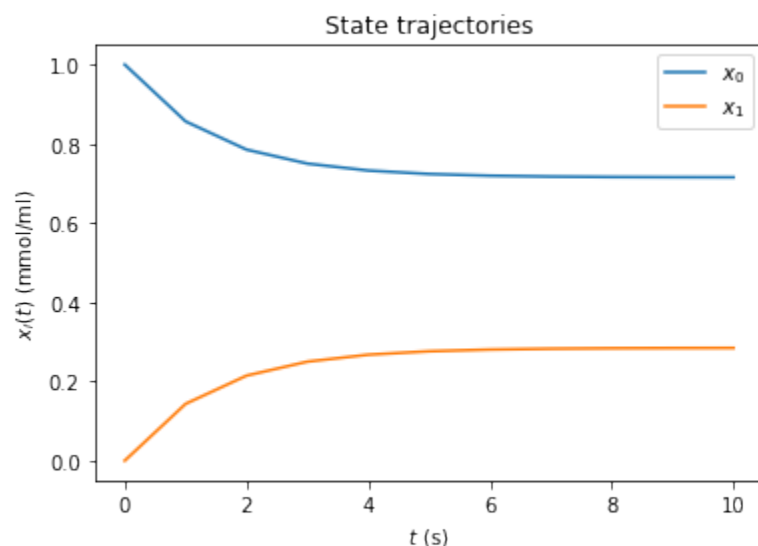
### 2.2.2 Load AMICI model

```
[3]: # load amici module (the usual starting point later for the analysis)
sys.path.insert(0, os.path.abspath(model_output_dir))
model_module = importlib.import_module(model_name)
model = model_module.getModel()
model.requireSensitivitiesForAllParameters()
model.setTimepoints(amici.DoubleVector(np.linspace(0, 10, 11)))
model.setParameterScale(amici.ParameterScaling_log10)
model.setParameters(amici.DoubleVector([-0.3, -0.7]))
solver = model.getSolver()
solver.setSensitivityMethod(amici.SensitivityMethod_forward)
solver.setSensitivityOrder(amici.SensitivityOrder_first)
```

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```
# how to run amici now:
rdata = amici.runAmiciSimulation(model, solver, None)
amici.plotting.plotStateTrajectories(rdata)
edata = amici.ExpData(rdata, 0.2, 0.0)
```



## 2.2.3 Optimize

```
[4]: # create objective function from amici model
# pesto.AmiciObjective is derived from pesto.Objective,
# the general pesto objective function class
objective = pypesto.AmiciObjective(model, solver, [edata], 1)

# create optimizer object which contains all information for doing the optimization
optimizer = pypesto.ScipyOptimizer(method='ls_trf')

#optimizer.solver = 'bfgs|meigo'
# if select meigo -> also set default values in solver_options
#optimizer.options = {'maxiter': 1000, 'disp': True} # = pesto.default_options_meigo()
#optimizer.startpoints = []
#optimizer.startpoint_method = 'lhs|uniform|something|function'
#optimizer.n_starts = 100

# see PestoOptions.m for more required options here
# returns OptimizationResult, see parameters.MS for what to return
# list of final optim results foreach multistart, times, hess, grad,
# flags, meta information (which optimizer -> optimizer.get_repr())

# create problem object containing all information on the problem to be solved
problem = pypesto.Problem(objective=objective,
                          lb=[-2,-2], ub=[2,2])

# maybe lb, ub = inf
# other constraints: kwargs, class pesto.Constraints
# constraints on pams, states, esp. pesto.AmiciConstraints (e.g. pam1 + pam2<= const)
```

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```
# if optimizer cannot handle -> error
# maybe also scaling / transformation of parameters encoded here

# do the optimization
result = pypesto.minimize(problem=problem,
                          optimizer=optimizer,
                          n_starts=10)

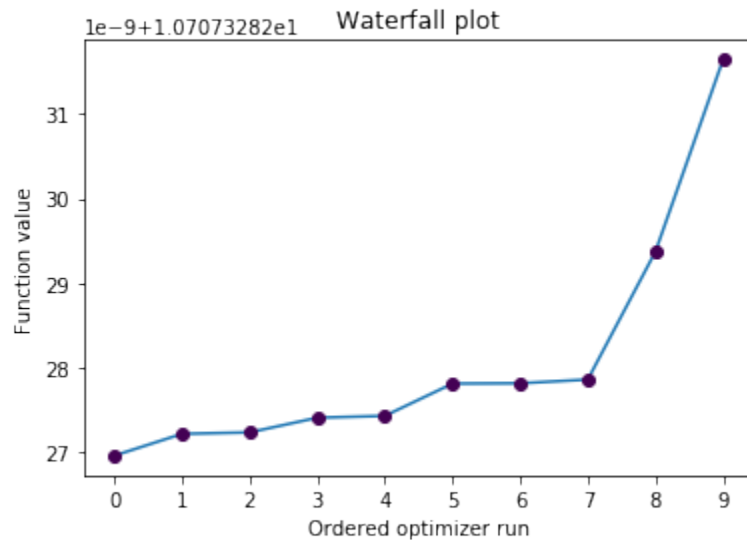
# optimize is a function since it does not need an internal memory,
# just takes input and returns output in the form of a Result object
# 'result' parameter: e.g. some results from somewhere -> pick best start points
```

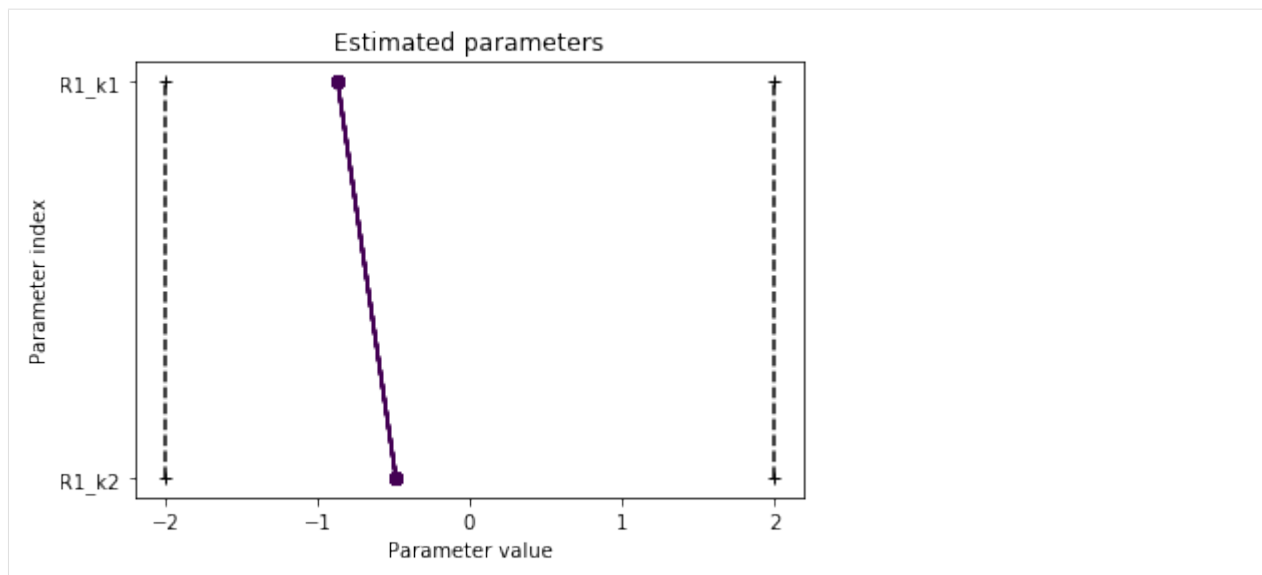
## 2.2.4 Visualize

```
[5]: # waterfall, parameter space, scatter plots, fits to data
# different functions for different plotting types
import pypesto.visualize
```

```
pypesto.visualize.waterfall(result)
pypesto.visualize.parameters(result)
```

```
[5]: <matplotlib.axes._subplots.AxesSubplot at 0x7f3dd2b98be0>
```





## 2.2.5 Data storage

```
[6]: # result = pypesto.storage.load('db_file.db')
```

## 2.2.6 Profiles

```
[7]: # there are three main parts: optimize, profile, sample. the overall structure of
    ↪ profiles and sampling
    # will be similar to optimizer like above.
    # we intend to only have just one result object which can be reused everywhere, but
    ↪ the problem of how to
    # not have one huge class but
    # maybe simplified views on it for optimization, profiles and sampling is still to be
    ↪ solved

    # profiler = pypesto.Profiler()

    # result = pypesto.profile(problem, profiler, result=None)
    # possibly pass result object from optimization to get good parameter guesses
```

## 2.2.7 Sampling

```
[8]: # sampler = pypesto.Sampler()

    # result = pypesto.sample(problem, sampler, result=None)

[9]: # open: how to parallelize. the idea is to use methods similar to those in pyabc for
    ↪ working on clusters.
    # one way would be to specify an additional 'engine' object passed to optimize(),
    ↪ profile(), sample(),
    # which in the default setting just does a for loop, but can also be customized.
```

## 2.3 Fixed parameters

In this notebook we will show how to use fixed parameters. Therefore, we employ our Rosenbrock example. We define two problems, where for the first problem all parameters are optimized, and for the second we fix some of them to specified values.

### 2.3.1 Define problem

```
[1]: import pypesto
import pypesto.visualize
import numpy as np
import scipy as sp
import matplotlib.pyplot as plt

%matplotlib inline

[2]: objective = pypesto.Objective(fun=sp.optimize.rosen,
                                   grad=sp.optimize.rosen_der,
                                   hess=sp.optimize.rosen_hess)

dim_full = 5
lb = -2 * np.ones((dim_full,1))
ub = 2 * np.ones((dim_full,1))

problem1 = pypesto.Problem(objective=objective, lb=lb, ub=ub)

x_fixed_indices = [1, 3]
x_fixed_vals = [1, 1]
problem2 = pypesto.Problem(objective=objective, lb=lb, ub=ub,
                           x_fixed_indices=x_fixed_indices,
                           x_fixed_vals=x_fixed_vals)
```

### 2.3.2 Optimize

```
[3]: optimizer = pypesto.ScipyOptimizer()
n_starts = 10

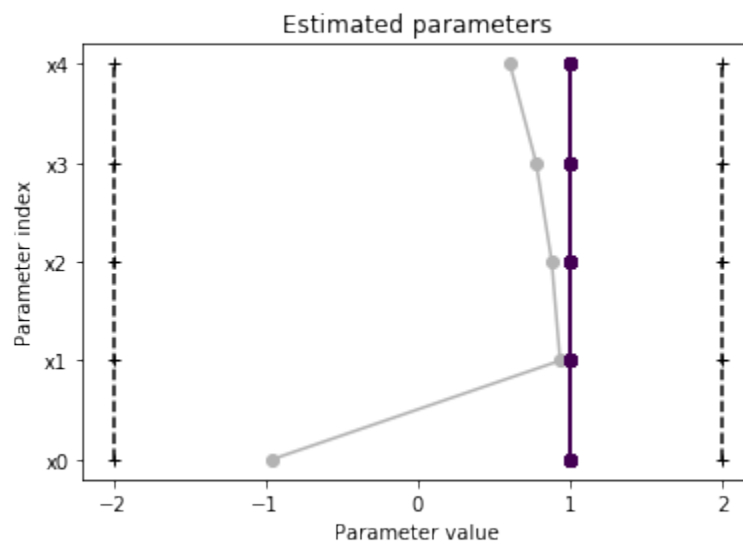
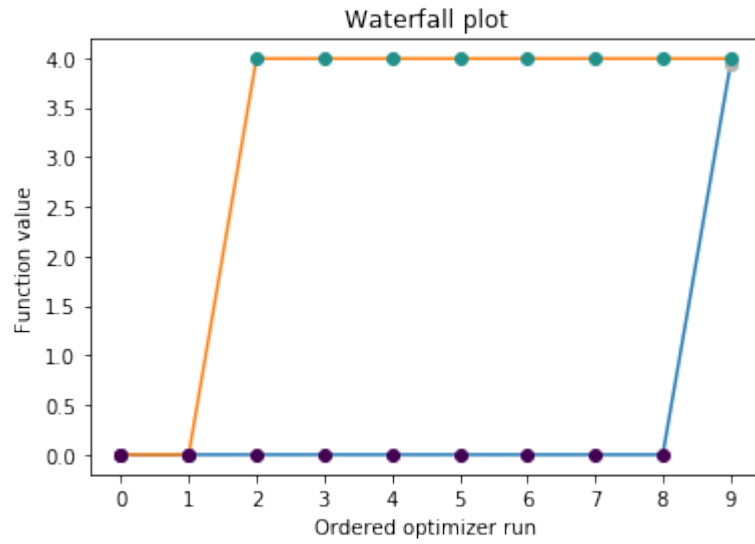
result1 = pypesto.minimize(problem=problem1, optimizer=optimizer,
                           n_starts=n_starts)
result2 = pypesto.minimize(problem=problem2, optimizer=optimizer,
                           n_starts=n_starts)
```

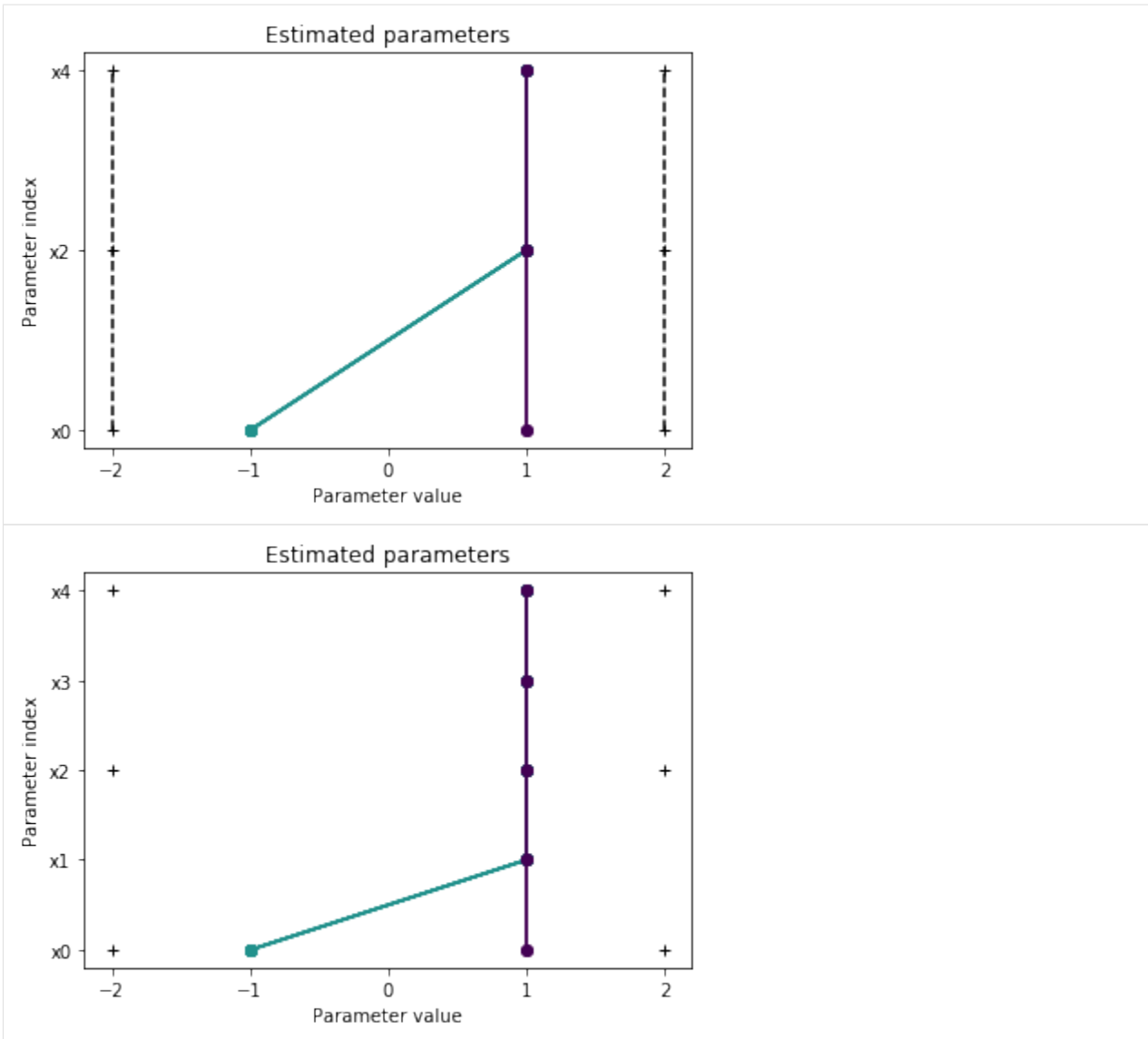
### 2.3.3 Visualize

```
[4]: fig, ax = plt.subplots()
pypesto.visualize.waterfall(result1, ax)
pypesto.visualize.waterfall(result2, ax)
pypesto.visualize.parameters(result1)
pypesto.visualize.parameters(result2)
pypesto.visualize.parameters(result2, free_indices_only=False)
```



```
[4]: <matplotlib.axes._subplots.AxesSubplot at 0x7f54c174de48>
```





```
[5]: result1.optimize_result.as_dataframe(['fval', 'x', 'grad'])
```

```
[5]:
```

|   | fval         | grad \  |
|---|--------------|---|
| 0 | 6.647442e-15 | [-9.471566723124671e-07, 2.1021349555995795e-0... |
| 1 | 3.457526e-13 | [-5.2800846471136764e-06, -3.3572245747142896e... |
| 2 | 3.977885e-13 | [2.849416601133684e-06, -1.631494200631376e-05... |
| 3 | 5.131069e-13 | [-1.7633333620389112e-05, 2.2702306040974444e-... |
| 4 | 1.136030e-12 | [-5.235885777815437e-06, 2.0492304488450417e-0... |
| 5 | 1.408337e-12 | [1.907331444582324e-05, 2.095463179570122e-05,... |
| 6 | 2.901510e-11 | [5.880961607340145e-05, -0.0001001725246473881... |
| 7 | 1.178049e-10 | [0.00034230906294693863, -0.000134688339183694... |
| 8 | 3.892358e-10 | [-0.0003125535760549204, -0.000540050381524208... |
| 9 | 3.930839e+00 | [1.0349712058044247e-05, 3.916386398739036e-06... |

```

                                x
0  [0.9999999965730911, 0.9999999954969394, 0.999...
1  [0.999999937976915, 0.9999998804645882, 0.999...
2  [1.0000000203239299, 1.0000000336259385, 1.000...
```

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```

3 [0.9999999656666152, 0.9999999752449003, 0.999...
4 [0.9999999555620058, 0.9999999239915387, 0.999...
5 [0.9999999800522175, 0.9999999123214094, 0.999...
6 [0.9999996346096833, 0.9999991203684541, 0.999...
7 [1.00000006892941309, 1.00000005262631377, 1.000...
8 [0.999999304112937, 0.9999993861314045, 1.0000...
9 [-0.9620510054878277, 0.9357393936941063, 0.88...

```

```
[6]: result2.optimize_result.as_dataframe(['fval', 'x', 'grad'])
```

```

[6]:      fval                                     grad \
0  1.848017e-13  [1.161320144703573e-05, nan, 1.138211418469940...
1  1.950306e-13  [1.5797936376845116e-05, nan, 8.69990872045727...
2  3.989975e+00  [3.708520157630346e-08, nan, 8.708029498088168...
3  3.989975e+00  [-2.0752946916502424e-08, nan, 1.7918193731319...
4  3.989975e+00  [-7.013172895753428e-07, nan, 6.60039187652859...
5  3.989975e+00  [4.8148038946926874e-06, nan, 5.98716656044703...
6  3.989975e+00  [-3.6444866702289858e-06, nan, -1.258053682496...
7  3.989975e+00  [-1.9515809019488017e-05, nan, 2.2359531416176...
8  3.989975e+00  [-2.509148223639457e-05, nan, 1.94825262340907...
9  3.989975e+00  [3.7141079881841677e-05, nan, -2.5976819306825...

                                     x
0  [1.0000000144803007, 1.0, 1.0000000113593952, ...
1  [1.0000000196981744, 1.0, 1.0000000086825436, ...
2  [-0.9949747467836382, 1.0, 1.0000000000869065,...
3  [-0.9949747468568538, 1.0, 1.0000000001788243,...
4  [-0.9949747477183607, 1.0, 1.00000000006587217,...
5  [-0.994974740735661, 1.0, 1.0000000005975216, 1...
6  [-0.9949747514440345, 1.0, 0.9999999874445739,...
7  [-0.9949747715350857, 1.0, 1.000000022314901, ...
8  [-0.9949747785931701, 1.0, 1.0000000194436385,...
9  [-0.9949746998147513, 1.0, 0.9999999740750298,...

```

```
[ ]:
```

## 2.4 AMICI Python example “Boehm”

This is an example using the model [boehm\_ProteomeRes2014.xml] model to demonstrate and test SBML import and AMICI Python interface.

```

[1]: import libsbml
import importlib
import amici
import pypesto
import os
import sys
import numpy as np
import matplotlib.pyplot as plt

# temporarily add the simulate file
sys.path.insert(0, 'boehm_JProteomeRes2014')

from benchmark_import import DataProvider

```

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```
# sbml file
sbml_file = 'boehm_JProteomeRes2014/boehm_JProteomeRes2014.xml'

# name of the model that will also be the name of the python module
model_name = 'boehm_JProteomeRes2014'

# output directory
model_output_dir = 'tmp/' + model_name
```

## 2.4.1 The example model

Here we use `libsbml` to show the reactions and species described by the model (this is independent of AMICI).

```
[2]: sbml_reader = libsbml.SBMLReader()
sbml_doc = sbml_reader.readSBML(os.path.abspath(sbml_file))
sbml_model = sbml_doc.getModel()
dir(sbml_doc)
print(os.path.abspath(sbml_file))
print('Species: ', [s.getId() for s in sbml_model.getListOfSpecies()])

print('\nReactions:')
for reaction in sbml_model.getListOfReactions():
    reactants = ' + '.join(['%s %s'%(int(r.getStoichiometry()) if r.
↪getStoichiometry() > 1 else '', r.getSpecies()) for r in reaction.
↪getListOfReactants()])
    products = ' + '.join(['%s %s'%(int(r.getStoichiometry()) if r.
↪getStoichiometry() > 1 else '', r.getSpecies()) for r in reaction.
↪getListOfProducts()])
    reversible = '<' if reaction.getReversible() else ''
    print('%3s: %10s %1s->%10s\t\t[%s]' % (reaction.getId(),
        reactants,
        reversible,
        products,
        libsbml.formulaToL3String(reaction.getKineticLaw().
↪getMath()))))

/home/yannik/pypesto/doc/example/boehm_JProteomeRes2014/boehm_JProteomeRes2014.xml
Species:  ['STAT5A', 'STAT5B', 'pApB', 'pApA', 'pBpB', 'nucpApA', 'nucpApB', 'nucpBpB
↪']

Reactions:
v1_v_0:  2 STAT5A  ->      pApA      [cyt * BaF3_Epo * STAT5A^2 * k_phos]
v2_v_1:  STAT5A +  STAT5B  ->      pApB      [cyt * BaF3_Epo * STAT5A *
↪STAT5B * k_phos]
v3_v_2:  2 STAT5B  ->      pBpB      [cyt * BaF3_Epo * STAT5B^2 * k_phos]
v4_v_3:  pApA      ->      nucpApA    [cyt * k_imp_homo * pApA]
v5_v_4:  pApB      ->      nucpApB    [cyt * k_imp_hetero * pApB]
v6_v_5:  pBpB      ->      nucpBpB    [cyt * k_imp_homo * pBpB]
v7_v_6:  nucpApA   ->  2 STAT5A      [nuc * k_exp_homo * nucpApA]
v8_v_7:  nucpApB   ->  STAT5A +  STAT5B [nuc * k_exp_hetero * nucpApB]
v9_v_8:  nucpBpB   ->  2 STAT5B      [nuc * k_exp_homo * nucpBpB]
```

## 2.4.2 Importing an SBML model, compiling and generating an AMICI module

Before we can use AMICI to simulate our model, the SBML model needs to be translated to C++ code. This is done by `amici.SbmlImporter`.

```
[3]: # Create an SbmlImporter instance for our SBML model
sbml_importer = amici.SbmlImporter(sbml_file)
```

In this example, we want to specify fixed parameters, observables and a  $\sigma$  parameter. Unfortunately, the latter two are not part of the [SBML standard](#). However, they can be provided to `amici.SbmlImporter.sbml2amici` as demonstrated in the following.

### Constant parameters

Constant parameters, i.e. parameters with respect to which no sensitivities are to be computed (these are often parameters specifying a certain experimental condition) are provided as a list of parameter names.

```
[4]: constantParameters = {'ratio', 'specC17'}
```

### Observables

We used SBML's `AssignmentRule` [http://sbml.org/Software/libSBML/5.13.0/docs/python-api/classlibsbml\\_1\\_1\\_rule.html](http://sbml.org/Software/libSBML/5.13.0/docs/python-api/classlibsbml_1_1_rule.html) as a non-standard way to specify *Model outputs* within the SBML file. These rules need to be removed prior to the model import (AMICI does at this time not support these Rules). This can be easily done using `amici.assignmentRules2observables()`.

In this example, we introduced parameters named `observable_*` as targets of the observable `AssignmentRules`. Where applicable we have `observable_*` `_sigma` parameters for  $\sigma$  parameters (see below).

```
[5]: # Retrieve model output names and formulae from AssignmentRules and remove the
↳respective rules
observables = amici.assignmentRules2observables(
    sbml_importer.sbml, # the libsbml model object
    filter_function=lambda variable: variable.getId().startswith('observable_')
↳and not variable.getId().endswith('_sigma')
)
print('Observables:', observables)

Observables: {'observable_pSTAT5A_rel': {'name': '', 'formula': '(100 * pApB + 200 *
↳pApA * specC17) / (pApB + STAT5A * specC17 + 2 * pApA * specC17)'}, 'observable_
↳pSTAT5B_rel': {'name': '', 'formula': '-(100 * pApB - 200 * pBpB * (specC17 - 1)) /
↳(STAT5B * (specC17 - 1) - pApB + 2 * pBpB * (specC17 - 1))'}, 'observable_rSTAT5A_
↳rel': {'name': '', 'formula': '(100 * pApB + 100 * STAT5A * specC17 + 200 * pApA *
↳specC17) / (2 * pApB + STAT5A * specC17 + 2 * pApA * specC17 - STAT5B * (specC17 -
↳1) - 2 * pBpB * (specC17 - 1))'}}
```

### $\sigma$ parameters

To specify measurement noise as a parameter, we simply provide a dictionary with (preexisting) parameter names as keys and a list of observable names as values to indicate which sigma parameter is to be used for which observable.

```
[6]: sigma_vals = ['sd_pSTAT5A_rel', 'sd_pSTAT5B_rel', 'sd_rSTAT5A_rel']
observable_names = observables.keys()
```

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```

sigmas = dict(zip(list(observable_names), sigma_vals))
print(sigmas)

{'observable_pSTAT5A_rel': 'sd_pSTAT5A_rel', 'observable_pSTAT5B_rel': 'sd_pSTAT5B_rel',
↳ 'observable_rSTAT5A_rel': 'sd_rSTAT5A_rel'}

```

## Generating the module

Now we can generate the python module for our model. `amici.SbmlImporter.sbml2amici` will symbolically derive the sensitivity equations, generate C++ code for model simulation, and assemble the python module.

```

[7]: sbml_importer.sbml2amici(model_name,
                             model_output_dir,
                             verbose=False,
                             observables=observables,
                             constantParameters=constantParameters,
                             sigmas=sigmas
                             )

```

## Importing the module and loading the model

If everything went well, we need to add the previously selected model output directory to our `PYTHON_PATH` and are then ready to load newly generated model:

```

[8]: sys.path.insert(0, os.path.abspath(model_output_dir))
model_module = importlib.import_module(model_name)

```

And get an instance of our model from which we can retrieve information such as parameter names:

```

[9]: model = model_module.getModel()

print("Model parameters:", list(model.getParameterIds()))
print("Model outputs:    ", list(model.getObservableIds()))
print("Model states:     ", list(model.getStateIds()))

Model parameters: ['Epo_degradation_BaF3', 'k_exp_hetero', 'k_exp_homo', 'k_imp_hetero',
↳ 'k_imp_homo', 'k_phos', 'sd_pSTAT5A_rel', 'sd_pSTAT5B_rel', 'sd_rSTAT5A_rel']
Model outputs:    ['observable_pSTAT5A_rel', 'observable_pSTAT5B_rel', 'observable_
↳ rSTAT5A_rel']
Model states:     ['STAT5A', 'STAT5B', 'pApB', 'pApA', 'pBpB', 'nucpApA', 'nucpApB',
↳ 'nucpBpB']

```

## 2.4.3 Running simulations and analyzing results

After importing the model, we can run simulations using `amici.runAmiciSimulation`. This requires a `Model` instance and a `Solver` instance. Optionally you can provide measurements inside an `ExpData` instance, as shown later in this notebook.

```

[10]: h5_file = 'boehm_JProteomeRes2014/data_boehm_JProteomeRes2014.h5'
dp = DataProvider(h5_file)

```

```
[11]: # set timepoints for which we want to simulate the model
timepoints = amici.DoubleVector(dp.get_timepoints())
model.setTimepoints(timepoints)

# set fixed parameters for which we want to simulate the model
model.setFixedParameters(amici.DoubleVector(np.array([0.693, 0.107])))

# set parameters to optimal values found in the benchmark collection
model.setParameterScale(2)
model.setParameters(amici.DoubleVector(np.array([-1.568917588,
-4.999704894,
-2.209698782,
-1.786006548,
4.990114009,
4.197735488,
0.585755271,
0.818982819,
0.498684404
])))

# Create solver instance
solver = model.getSolver()

# Run simulation using model parameters from the benchmark collection and default_
↳ solver options
rdata = amici.runAmiciSimulation(model, solver)
```

```
[12]: # Create edata
edata = amici.ExpData(rdata, 1.0, 0)

# set observed data
edata.setObservedData(amici.DoubleVector(dp.get_measurements()[0][:, 0]), 0)
edata.setObservedData(amici.DoubleVector(dp.get_measurements()[0][:, 1]), 1)
edata.setObservedData(amici.DoubleVector(dp.get_measurements()[0][:, 2]), 2)

# set standard deviations to optimal values found in the benchmark collection
edata.setObservedDataStdDev(amici.DoubleVector(np.array(16*[10**0.585755271])), 0)
edata.setObservedDataStdDev(amici.DoubleVector(np.array(16*[10**0.818982819])), 1)
edata.setObservedDataStdDev(amici.DoubleVector(np.array(16*[10**0.498684404])), 2)
```

```
[13]: rdata = amici.runAmiciSimulation(model, solver, edata)

print('Chi2 value reported in benchmark collection: 47.9765479')
print('chi2 value using AMICI:')
print(rdata['chi2'])

Chi2 value reported in benchmark collection: 47.9765479
chi2 value using AMICI:
47.97654266893465
```

## 2.4.4 Run optimization using pyPESTO

```
[14]: # create objective function from amici model
# pesto.AmiciObjective is derived from pesto.Objective,
# the general pesto objective function class
```

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```

model.requireSensitivitiesForAllParameters()

solver.setSensitivityMethod(amici.SensitivityMethod_forward)
solver.setSensitivityOrder(amici.SensitivityOrder_first)

objective = pypesto.AmiciObjective(model, solver, [edata], 1)

```

```

[15]: # create optimizer object which contains all information for doing the optimization
optimizer = pypesto.ScipyOptimizer()

optimizer.solver = 'bfgs'

```

```

[16]: # create problem object containing all information on the problem to be solved
x_names = ['x' + str(j) for j in range(0, 9)]
problem = pypesto.Problem(objective=objective,
                           lb=-5*np.ones((9)), ub=5*np.ones((9)),
                           x_names=x_names)

```

```

[17]: # do the optimization
result = pypesto.minimize(problem=problem,
                           optimizer=optimizer,
                           n_starts=10) # 200

```

```

[Warning] AMICI:CVODES:CVode:ERR_FAILURE: AMICI ERROR: in module CVODES in function_
↳ CVode : At t = 221.821 and h = 3.00478e-06, the error test failed repeatedly or_
↳ with |h| = hmin.
[Warning] AMICI:simulation: AMICI forward simulation failed at t = 221.821149:
AMICI failed to integrate the forward problem

```

```

[Warning] AMICI:CVODES:CVode:ERR_FAILURE: AMICI ERROR: in module CVODES in function_
↳ CVode : At t = 221.821 and h = 3.00478e-06, the error test failed repeatedly or_
↳ with |h| = hmin.
[Warning] AMICI:simulation: AMICI forward simulation failed at t = 221.821149:
AMICI failed to integrate the forward problem

```

```

[Warning] AMICI:CVODES:CVode:ERR_FAILURE: AMICI ERROR: in module CVODES in function_
↳ CVode : At t = 221.821 and h = 3.00478e-06, the error test failed repeatedly or_
↳ with |h| = hmin.
[Warning] AMICI:simulation: AMICI forward simulation failed at t = 221.821149:
AMICI failed to integrate the forward problem

```

```

[Warning] AMICI:CVODES:CVode:ERR_FAILURE: AMICI ERROR: in module CVODES in function_
↳ CVode : At t = 147.199 and h = 2.90261e-05, the error test failed repeatedly or_
↳ with |h| = hmin.
[Warning] AMICI:simulation: AMICI forward simulation failed at t = 147.198629:
AMICI failed to integrate the forward problem

```

```

[Warning] AMICI:CVODES:CVode:ERR_FAILURE: AMICI ERROR: in module CVODES in function_
↳ CVode : At t = 147.199 and h = 2.90261e-05, the error test failed repeatedly or_
↳ with |h| = hmin.
[Warning] AMICI:simulation: AMICI forward simulation failed at t = 147.198629:
AMICI failed to integrate the forward problem

```

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```
[Warning] AMICI:CVODES:CVode:ERR_FAILURE: AMICI ERROR: in module CVODES in function_
↳CVode : At t = 147.199 and h = 2.90261e-05, the error test failed repeatedly or_
↳with |h| = hmin.
[Warning] AMICI:simulation: AMICI forward simulation failed at t = 147.198629:
AMICI failed to integrate the forward problem

[Warning] AMICI:CVODES:CVode:ERR_FAILURE: AMICI ERROR: in module CVODES in function_
↳CVode : At t = 198 and h = 2.97875e-05, the error test failed repeatedly or with_
↳|h| = hmin.
[Warning] AMICI:simulation: AMICI forward simulation failed at t = 197.999609:
AMICI failed to integrate the forward problem

[Warning] AMICI:CVODES:CVode:ERR_FAILURE: AMICI ERROR: in module CVODES in function_
↳CVode : At t = 197.697 and h = 2.98464e-05, the error test failed repeatedly or_
↳with |h| = hmin.
[Warning] AMICI:simulation: AMICI forward simulation failed at t = 197.696730:
AMICI failed to integrate the forward problem

[Warning] AMICI:CVODES:CVode:ERR_FAILURE: AMICI ERROR: in module CVODES in function_
↳CVode : At t = 197.697 and h = 2.98464e-05, the error test failed repeatedly or_
↳with |h| = hmin.
[Warning] AMICI:simulation: AMICI forward simulation failed at t = 197.696730:
AMICI failed to integrate the forward problem

[Warning] AMICI:CVODES:CVode:ERR_FAILURE: AMICI ERROR: in module CVODES in function_
↳CVode : At t = 197.697 and h = 2.98464e-05, the error test failed repeatedly or_
↳with |h| = hmin.
[Warning] AMICI:simulation: AMICI forward simulation failed at t = 197.696730:
AMICI failed to integrate the forward problem

[Warning] AMICI:CVODES:CVode:ERR_FAILURE: AMICI ERROR: in module CVODES in function_
↳CVode : At t = 66.4603 and h = 6.88533e-06, the error test failed repeatedly or_
↳with |h| = hmin.
[Warning] AMICI:simulation: AMICI forward simulation failed at t = 66.460272:
AMICI failed to integrate the forward problem

[Warning] AMICI:CVODES:CVode:ERR_FAILURE: AMICI ERROR: in module CVODES in function_
↳CVode : At t = 66.3735 and h = 8.78908e-06, the error test failed repeatedly or_
↳with |h| = hmin.
[Warning] AMICI:simulation: AMICI forward simulation failed at t = 66.373478:
AMICI failed to integrate the forward problem

[Warning] AMICI:CVODES:CVode:ERR_FAILURE: AMICI ERROR: in module CVODES in function_
↳CVode : At t = 85.8974 and h = 2.05376e-05, the error test failed repeatedly or_
↳with |h| = hmin.
[Warning] AMICI:simulation: AMICI forward simulation failed at t = 85.897359:
AMICI failed to integrate the forward problem
```

## 2.4.5 Visualization

Create waterfall and parameter plot

```
[18]: # waterfall, parameter space,
import pypesto.visualize
```

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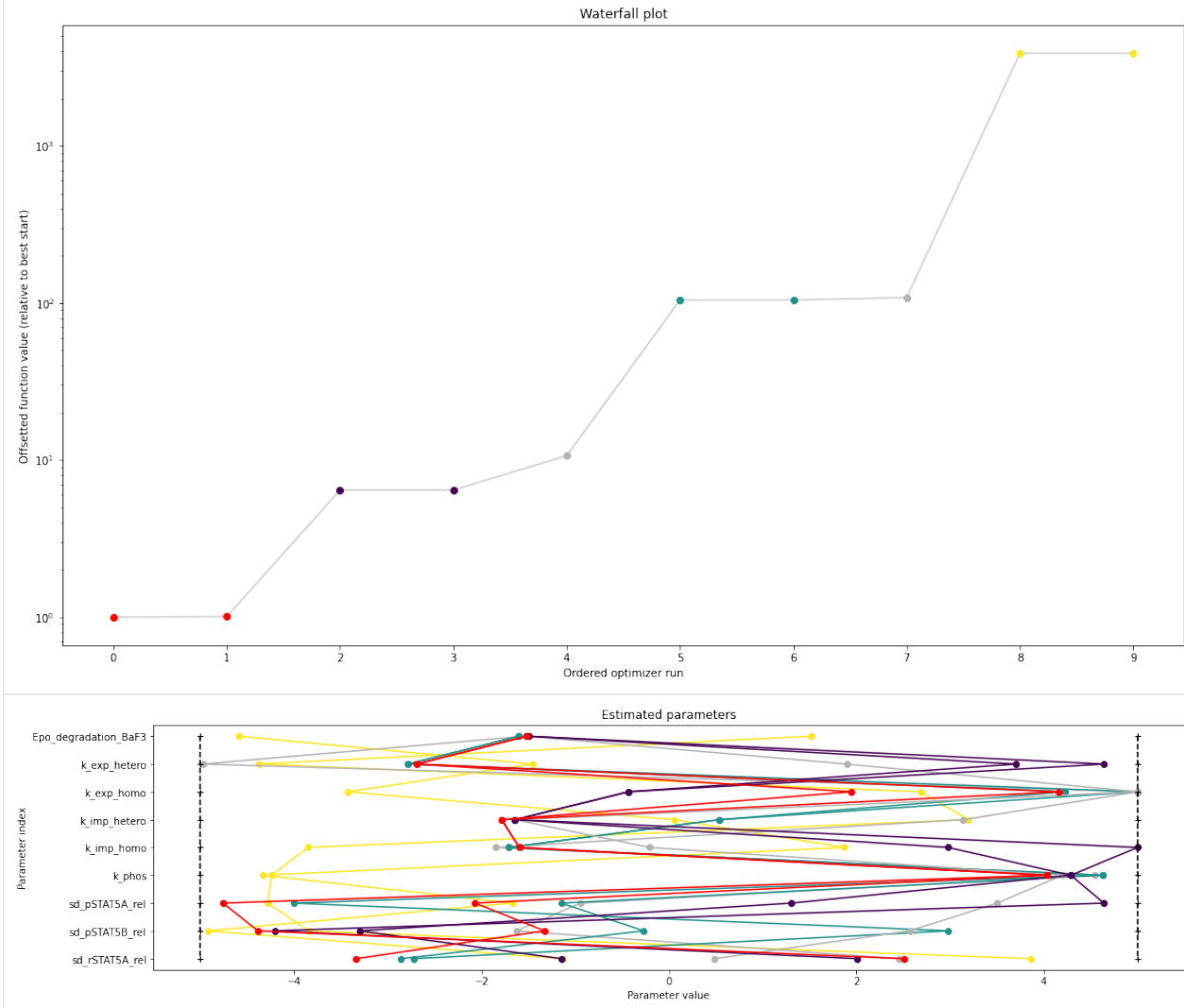
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```

pypesto.visualize.waterfall(result)
pypesto.visualize.parameters(result)

```

```
[18]: <matplotlib.axes._subplots.AxesSubplot at 0x7f3bc5881c10>
```



## 2.5 Model import using the Petab format

In this notebook, we illustrate using pyPESTO together with PETab and AMICI. We employ models from the benchmark collection, which we first download:

```

[1]: import pypesto
import amici
import petab

import os
import numpy as np

```

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```
import matplotlib.pyplot as plt

%matplotlib inline

# Download benchmark models - Note: 200MB :(
!git clone --depth 1 https://github.com/Benchmarking-Initiative/Benchmark-Models-
↳PETab.git tmp/benchmark-models || (cd tmp/benchmark-models && git pull)

folder_base = "tmp/benchmark-models/Benchmark-Models/"

fatal: destination path 'tmp/benchmark-models' already exists and is not an empty_
↳directory.
Already up to date.
```

### 2.5.1 Manage PETab model

A PETab problem comprises all the information on the model, the data and the parameters to perform parameter estimation:

```
[2]: # a collection of models that can be simulated

#model_name = "Zheng_PNAS2012"
model_name = "Boehm_JProteomeRes2014"
#model_name = "Fujita_SciSignal2010"
#model_name = "Sneyd_PNAS2002"
#model_name = "Borghans_BiophysChem1997"
#model_name = "Elowitz_Nature2000"
#model_name = "Crauste_CellSystems2017"
#model_name = "Lucarelli_CellSystems2018"
#model_name = "Schwen_PONE2014"
#model_name = "Blasi_CellSystems2016"

# the yaml configuration file links to all needed files
yaml_config = os.path.join(folder_base, model_name, model_name + '.yaml')

# create a petab problem
petab_problem = petab.Problem.from_yaml(yaml_config)
```

### 2.5.2 Import model to AMICI

The model must be imported to AMICI:

```
[3]: importer = pypesto.PetabImporter(petab_problem)

model = importer.create_model()

print("Model parameters:", list(model.getParameterIds()), '\n')
print("Model const parameters:", list(model.getFixedParameterIds()), '\n')
print("Model outputs:      ", list(model.getObservableIds()), '\n')
print("Model states:       ", list(model.getStateIds()), '\n')
```

```

Model parameters: ['Epo_degradation_BaF3', 'k_exp_hetero', 'k_exp_homo', 'k_imp_hetero',
↳ 'k_imp_homo', 'k_phos', 'ratio', 'specC17', 'noiseParameter1_pSTAT5A_rel',
↳ 'noiseParameter1_pSTAT5B_rel', 'noiseParameter1_rSTAT5A_rel']

Model const parameters: []

Model outputs:      ['pSTAT5A_rel', 'pSTAT5B_rel', 'rSTAT5A_rel']

Model states:       ['STAT5A', 'STAT5B', 'pApB', 'pApA', 'pBpB', 'nucpApA', 'nucpApB',
↳ 'nucpBpB']

```

### 2.5.3 Create objective function

```

[4]: import libsbml
converter_config = libsbml.SBMLLocalParameterConverter()\
    .getDefaultProperties()
petab_problem.sbml_document.convert(converter_config)

obj = importer.create_objective()

# for some models, hyperparameters need to be adjusted
#obj.amici_solver.setMaxSteps(10000)
#obj.amici_solver.setRelativeTolerance(1e-7)
#obj.amici_solver.setAbsoluteTolerance(1e-7)

ret = obj(petab_problem.x_nominal_scaled, sensi_orders=(0,1), return_dict=True)
print(ret)

{'fval': 138.22199677513575, 'grad': array([ 2.20386015e-02,  5.53227506e-02,  5.
↳ 78886452e-03,  5.40656415e-03,
    -4.51595809e-05,  7.91163446e-03,  0.00000000e+00,  1.07840959e-02,
    2.40378735e-02,  1.91919657e-02,  0.00000000e+00]), 'hess': array([[ -2.
↳ 11105595e+03, -5.89390039e-01, -1.07159910e+02,
    -2.81393973e+03, -8.94333861e-06,  7.86055092e+02,
    0.00000000e+00,  0.00000000e+00,  0.00000000e+00,
    0.00000000e+00,  0.00000000e+00],
    [-5.89390039e-01, -1.91513744e-03,  1.72774945e-01,
    -7.12558479e-01,  3.69774927e-08,  3.20531692e-01,
    0.00000000e+00,  0.00000000e+00,  0.00000000e+00,
    0.00000000e+00,  0.00000000e+00],
    [-1.07159910e+02,  1.72774945e-01, -6.99839693e+01,
    -1.61497679e+02, -7.16323554e-06,  8.83572656e+01,
    0.00000000e+00,  0.00000000e+00,  0.00000000e+00,
    0.00000000e+00,  0.00000000e+00],
    [-2.81393973e+03, -7.12558479e-01, -1.61497679e+02,
    -3.76058352e+03, -8.40044683e-06,  1.04136909e+03,
    0.00000000e+00,  0.00000000e+00,  0.00000000e+00,
    0.00000000e+00,  0.00000000e+00],
    [-8.94333861e-06,  3.69774927e-08, -7.16323554e-06,
    -8.40044683e-06, -2.86438192e-10,  2.24927732e-04,
    0.00000000e+00,  0.00000000e+00,  0.00000000e+00,
    0.00000000e+00,  0.00000000e+00],
    [ 7.86055092e+02,  3.20531692e-01,  8.83572656e+01,
    1.04136909e+03,  2.24927732e-04, -9.29902113e+02,
    0.00000000e+00,  0.00000000e+00,  0.00000000e+00,
    0.00000000e+00,  0.00000000e+00])

```

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```

    0.00000000e+00, 0.00000000e+00],
  [ 0.00000000e+00, 0.00000000e+00, 0.00000000e+00,
    0.00000000e+00, 0.00000000e+00, 0.00000000e+00,
    0.00000000e+00, 0.00000000e+00, 0.00000000e+00,
    0.00000000e+00, 0.00000000e+00],
  [ 0.00000000e+00, 0.00000000e+00, 0.00000000e+00,
    0.00000000e+00, 0.00000000e+00, 0.00000000e+00,
    0.00000000e+00, 0.00000000e+00, 0.00000000e+00,
    0.00000000e+00, 0.00000000e+00],
  [ 0.00000000e+00, 0.00000000e+00, 0.00000000e+00,
    0.00000000e+00, 0.00000000e+00, 0.00000000e+00,
    0.00000000e+00, 0.00000000e+00, 0.00000000e+00,
    0.00000000e+00, 0.00000000e+00],
  [ 0.00000000e+00, 0.00000000e+00, 0.00000000e+00,
    0.00000000e+00, 0.00000000e+00, 0.00000000e+00,
    0.00000000e+00, 0.00000000e+00, 0.00000000e+00,
    0.00000000e+00, 0.00000000e+00],
  [ 0.00000000e+00, 0.00000000e+00, 0.00000000e+00,
    0.00000000e+00, 0.00000000e+00, 0.00000000e+00,
    0.00000000e+00, 0.00000000e+00, 0.00000000e+00,
    0.00000000e+00, 0.00000000e+00]]), 'res': array([], dtype=float64), 'sres':
→array([], shape=(0, 11), dtype=float64), 'rdatas': [<amici.numpy.ReturnDataView
→object at 0x7f247cedec10>]}

```

For debugging: There is an alternative way of computing the function, in amici directly.

```

[5]: import libsbml
converter_config = libsbml.SBMLLocalParameterConverter()\
    .getDefaultProperties()
petab_problem.sbml_document.convert(converter_config)

obj2 = importer.create_objective()

obj2.use_amici_petab_simulate = True

# for some models, hyperparameters need to be adjusted
#obj2.amici_solver.setMaxSteps(int(1e8))
#obj2.amici_solver.setRelativeTolerance(1e-3)
#obj2.amici_solver.setAbsoluteTolerance(1e-3)

ret2 = obj2(petab_problem.x_nominal_scaled, sensi_orders=(0,1), return_dict=True)
print(ret2)

{'fval': 138.22199677513575, 'grad': array([ 2.20386015e-02,  5.53227506e-02,  5.
→78886452e-03,  5.40656415e-03,
    -4.51595809e-05,  7.91163446e-03,  0.00000000e+00,  1.07840959e-02,
    2.40378735e-02,  1.91919657e-02,  0.00000000e+00]), 'hess': array([[ -2.
→11105595e+03, -5.89390039e-01, -1.07159910e+02,
    -2.81393973e+03, -8.94333861e-06,  7.86055092e+02,
    0.00000000e+00,  0.00000000e+00,  0.00000000e+00,
    0.00000000e+00,  0.00000000e+00],
    [-5.89390039e-01, -1.91513744e-03,  1.72774945e-01,
    -7.12558479e-01,  3.69774927e-08,  3.20531692e-01,
    0.00000000e+00,  0.00000000e+00,  0.00000000e+00,
    0.00000000e+00,  0.00000000e+00],
    [-1.07159910e+02,  1.72774945e-01, -6.99839693e+01,
    -1.61497679e+02, -7.16323554e-06,  8.83572656e+01,

```

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```

0.00000000e+00, 0.00000000e+00, 0.00000000e+00,
0.00000000e+00, 0.00000000e+00],
[-2.81393973e+03, -7.12558479e-01, -1.61497679e+02,
-3.76058352e+03, -8.40044683e-06, 1.04136909e+03,
0.00000000e+00, 0.00000000e+00, 0.00000000e+00,
0.00000000e+00, 0.00000000e+00],
[-8.94333861e-06, 3.69774927e-08, -7.16323554e-06,
-8.40044683e-06, -2.86438192e-10, 2.24927732e-04,
0.00000000e+00, 0.00000000e+00, 0.00000000e+00,
0.00000000e+00, 0.00000000e+00],
[ 7.86055092e+02, 3.20531692e-01, 8.83572656e+01,
1.04136909e+03, 2.24927732e-04, -9.29902113e+02,
0.00000000e+00, 0.00000000e+00, 0.00000000e+00,
0.00000000e+00, 0.00000000e+00],
[ 0.00000000e+00, 0.00000000e+00, 0.00000000e+00,
0.00000000e+00, 0.00000000e+00, 0.00000000e+00,
0.00000000e+00, 0.00000000e+00, 0.00000000e+00,
0.00000000e+00, 0.00000000e+00],
[ 0.00000000e+00, 0.00000000e+00, 0.00000000e+00,
0.00000000e+00, 0.00000000e+00, 0.00000000e+00,
0.00000000e+00, 0.00000000e+00, 0.00000000e+00,
0.00000000e+00, 0.00000000e+00],
[ 0.00000000e+00, 0.00000000e+00, 0.00000000e+00,
0.00000000e+00, 0.00000000e+00, 0.00000000e+00,
0.00000000e+00, 0.00000000e+00, 0.00000000e+00,
0.00000000e+00, 0.00000000e+00],
[ 0.00000000e+00, 0.00000000e+00, 0.00000000e+00,
0.00000000e+00, 0.00000000e+00, 0.00000000e+00,
0.00000000e+00, 0.00000000e+00, 0.00000000e+00,
0.00000000e+00, 0.00000000e+00],
[ 0.00000000e+00, 0.00000000e+00, 0.00000000e+00,
0.00000000e+00, 0.00000000e+00, 0.00000000e+00,
0.00000000e+00, 0.00000000e+00, 0.00000000e+00,
0.00000000e+00, 0.00000000e+00],
[ 0.00000000e+00, 0.00000000e+00, 0.00000000e+00,
0.00000000e+00, 0.00000000e+00, 0.00000000e+00,
0.00000000e+00, 0.00000000e+00, 0.00000000e+00,
0.00000000e+00, 0.00000000e+00]], 'res': array([], dtype=float64), 'sres':
↪array([], shape=(0, 11), dtype=float64), 'rdatas': [<amici.numpy.ReturnDataView_
↪object at 0x7f247cba3290>]}

```

A finite difference check whether the computed gradient is accurate:

```

[6]: problem = importer.create_problem(obj)

objective = problem.objective

ret = objective(petab_problem.x_nominal_free_scaled, sensi_orders=(0,1))
print(ret)

(138.22199677513575, array([ 2.20386015e-02,  5.53227506e-02,  5.78886452e-03,  5.
↪40656415e-03,
-4.51595809e-05,  7.91163446e-03,  1.07840959e-02,  2.40378735e-02,
1.91919657e-02]))

```

```

[7]: eps = 1e-4

def fd(x):
    grad = np.zeros_like(x)
    j = 0
    for i, xi in enumerate(x):

```

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```

        mask = np.zeros_like(x)
        mask[i] += eps
        valinc, _ = objective(x+mask, sensi_orders=(0,1))
        valdec, _ = objective(x-mask, sensi_orders=(0,1))
        grad[j] = (valinc - valdec) / (2*eps)
        j += 1
    return grad

fdval = fd(petab_problem.x_nominal_free_scaled)
print("fd: ", fdval)
print("l2 difference: ", np.linalg.norm(ret[1] - fdval))

fd: [0.02493368 0.05309659 0.00530587 0.01291083 0.00587754 0.01473653
      0.01078279 0.02403657 0.01919066]
l2 difference: 0.012310244824532144

```

## 2.5.4 Run optimization

```
[8]: print(problem.x_fixed_indices, problem.x_free_indices)
```

```
[6, 10] [0, 1, 2, 3, 4, 5, 7, 8, 9]
```

```
[9]: optimizer = pypesto.ScipyOptimizer()
```

```
engine = pypesto.SingleCoreEngine()
engine = pypesto.MultiProcessEngine()
```

```
# do the optimization
result = pypesto.minimize(problem=problem, optimizer=optimizer,
                          n_starts=10, engine=engine)
```

Engine set up to use up to 4 processes in total. The number was automatically\_  
 ↪determined and might not be appropriate on some systems.

## 2.5.5 Visualize

```
[10]: result.optimize_result.get_for_key('fval')
```

```
[10]: [138.22197383818877,
      145.75940996955092,
      149.58861509227683,
      154.73313632726362,
      166.42016015420128,
      249.7445771549656,
      249.74598291093008,
      249.74598526715747,
      249.74599456039678,
      249.74599744358338]
```

```
[11]: import pypesto.visualize
```

```
ref = pypesto.visualize.create_references(x=petab_problem.x_nominal_scaled,
    ↪fval=obj(petab_problem.x_nominal_scaled))
```

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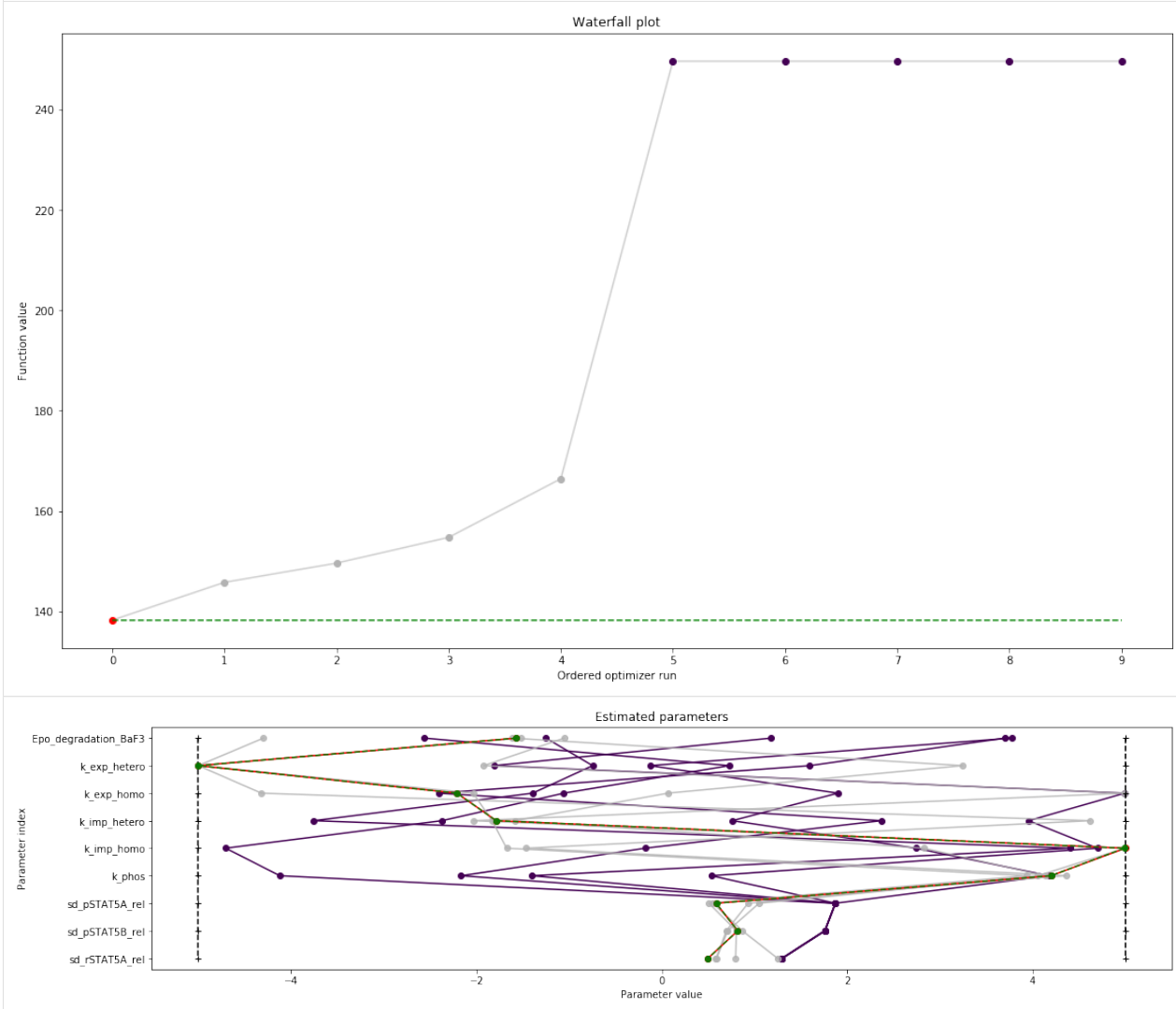
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```

pypesto.visualize.waterfall(result, reference=ref, scale_y='lin')
pypesto.visualize.parameters(result, reference=ref)

```

```
[11]: <matplotlib.axes._subplots.AxesSubplot at 0x7f247bd8bb90>
```



## 2.6 Download the examples as notebooks

- Rosenbrock
- Conversion reaction
- Fixed parameters
- Boehm model
- Petab import

**Note:** Some of the notebooks have extra dependencies.



## 3.1 Contribute documentation

To make pypesto easily usable, we are committed to documenting extensively. This involves in particular documenting the functionality of methods and classes, the purpose of single lines of code, and giving usage examples. The documentation is hosted on [pypesto.readthedocs.io](https://pypesto.readthedocs.io) and updated automatically every time the master branch on [github.com/icb-dcm/pypesto](https://github.com/icb-dcm/pypesto) is updated. To compile the documentation locally, use:

```
cd doc
make html
```

## 3.2 Contribute tests

Tests are located in the `test` folder. All files starting with `test_` contain tests and are automatically run on Travis CI. To run them manually, type:

```
python3 -m pytest test
```

or alternatively:

```
python3 -m unittest test
```

You can also run specific tests.

Tests can be written with [pytest](#) or the [unittest](#) module.

### 3.2.1 PEP8

We try to respect the [PEP8](#) coding standards. We run [flake8](#) as part of the tests. If flake8 complains, the tests won't pass. You can run it via:

```
./run_flake8.sh
```

in Linux from the base directory, or directly from python. More, you can use the tool [autopep8](#) to automatically fix various coding issues.

### 3.3 Contribute code

If you start working on a new feature or a fix, if not already done, please create an issue on github shortly describing your plans and assign it to yourself.

To get your code merged, please:

1. create a pull request to develop
2. if not already done in a commit message already, use the pull request description to reference and automatically close the respective issue (see <https://help.github.com/articles/closing-issues-using-keywords/>)
3. check that all tests on travis pass
4. check that the documentation is up-to-date
5. request a code review

General notes:

- Internally, we use `numpy` for arrays. In particular, vectors are represented as arrays of shape `(n,)`.
- Use informative commit messages.

New features and bug fixes are continuously added to the develop branch. On every merge to master, the version number in `pypesto/version.py` should be incremented as described below.

### 4.1 Versioning scheme

For version numbers, we use `A.B.C`, where

- `C` is increased for bug fixes,
- `B` is increased for new features and minor API breaking changes,
- `A` is increased for major API breaking changes.

### 4.2 Creating a new release

After new commits have been added to the develop branch, changes can be merged to master and a new version of pyPESTO can be released. Every merge to master should coincide with an incremented version number and a git tag on the respective merge commit.

#### 4.2.1 Merge into master

1. create a pull request from develop to master
2. check that all tests on travis pass
3. check that the documentation is up-to-date
4. adapt the version number in the file `pesto/version.py` (see above)
5. update the release notes in `doc/releasenotes.rst`
6. request a code review

7. merge into the origin master branch

To be able to actually perform the merge, sufficient rights may be required. Also, at least one review is required.

### 4.2.2 Creating a release on github

After merging into master, create a new release on Github. In the release form:

- specify a tag with the new version as specified in `pesto/version.py`, prefixed with `v` (e.g. `v0.0.1`)
- include the latest additions to `doc/releasenotes.rst` in the release description

Tagging the release commit will automatically trigger deployment of the new version to pypi.

```
class pypesto.objective.Objective (fun=None, grad=None, hess=None, hessp=None,  
                                res=None, sres=None, fun_accept_sensi_orders=False,  
                                res_accept_sensi_orders=False, x_names=None, op-  
                                tions=None)
```

Bases: object

The objective class is a simple wrapper around the objective function, giving a standardized way of calling. Apart from that, it manages several things including fixing of parameters and history.

### Parameters

- **fun** (*callable, optional*) – The objective function to be minimized. If it only computes the objective function value, it should be of the form

```
fun(x) -> float
```

where x is an 1-D array with shape (n,), and n is the parameter space dimension.

- **grad** (*callable, bool, optional*) – Method for computing the gradient vector. If it is a callable, it should be of the form

```
grad(x) -> array_like, shape (n,).
```

If its value is True, then fun should return the gradient as a second output.

- **hess** (*callable, optional*) – Method for computing the Hessian matrix. If it is a callable, it should be of the form

```
hess(x) -> array, shape (n,n).
```

If its value is True, then fun should return the gradient as a second, and the Hessian as a third output, and grad should be True as well.

- **hessp** (*callable, optional*) – Method for computing the Hessian vector product, i.e.

```
hessp(x, v) -> array_like, shape (n,)
```

computes the product  $H*v$  of the Hessian of fun at x with v.

- **res** (*{callable, bool}, optional*) – Method for computing residuals, i.e.  
`res(x) -> array_like, shape(m,)`.
- **sres** (*callable, optional*) – Method for computing residual sensitivities. If its is a callable, it should be of the form  
`sres(x) -> array, shape (m,n)`.  
If its value is True, then res should return the residual sensitivities as a second output.
- **fun\_accept\_sensi\_orders** (*bool, optional*) – Flag indicating whether fun takes sensi\_orders as an argument. Default: False.
- **res\_accept\_sensi\_orders** (*bool, optional*) – Flag indicating whether res takes sensi\_orders as an argument. Default: False
- **x\_names** (*list of str*) – Parameter names. None if no names provided, otherwise a list of str, length dim\_full (as in the Problem class). Can be read by the problem.
- **options** (*pypesto.ObjectiveOptions, optional*) – Options as specified in pypesto.ObjectiveOptions.

#### history

For storing the call history. Initialized by the optimizer in reset\_history().

**Type** pypesto.ObjectiveHistory

#### preprocess

Preprocess input values to `__call__`.

**Type** callable

#### postprocess

Postprocess output values from `__call__`.

**Type** callable

#### sensitivity\_orders

Temporary variable to store requested sensitivity orders

**Type** tuple

## Notes

preprocess, postprocess are configured in `update_from_problem()` and can be reset using the `reset()` method.

If `fun_accept_sensi_orders` resp. `res_accept_sensi_orders` is True, fun resp. res can also return dictionaries instead of tuples. In that case, they are expected to follow the naming conventions in `constants.py`. This is of interest, because when `__call__` is called with `return_dict = True`, the full dictionary is returned, which can contain e.g. also simulation data or debugging information.

`__call__` (*x, sensi\_orders: tuple = (0, ), mode='mode\_fun', return\_dict=False*)

Method to obtain arbitrary sensitivities. This is the central method which is always called, also by the `get_*` methods.

There are different ways in which an optimizer calls the objective function, and in how the objective function provides information (e.g. derivatives via separate functions or along with the function values). The different calling modes increase efficiency in space and time and make the objective flexible.

#### Parameters

- **x** (*array\_like*) – The parameters for which to evaluate the objective function.

- **sensi\_orders** (*tuple*) – Specifies which sensitivities to compute, e.g. (0,1) -> fval, grad.
- **mode** (*str*) – Whether to compute function values or residuals.

**\_\_init\_\_** (*fun=None, grad=None, hess=None, hessp=None, res=None, sres=None, fun\_accept\_sensi\_orders=False, res\_accept\_sensi\_orders=False, x\_names=None, options=None*)

Initialize self. See help(type(self)) for accurate signature.

**check\_grad** (*x, x\_indices=None, eps=1e-05, verbosity=1, mode='mode\_fun'*) → pandas.core.frame.DataFrame

Compare gradient evaluation: Firstly approximate via finite differences, and secondly use the objective gradient.

#### Parameters

- **x** (*array\_like*) – The parameters for which to evaluate the gradient.
- **x\_indices** (*array\_like, optional*) – List of index values for which to compute gradients. Default: all.
- **eps** (*float, optional*) – Finite differences step size. Default: 1e-5.
- **verbosity** (*int*) – Level of verbosity for function output. \* 0: no output, \* 1: summary for all parameters, \* 2: summary for individual parameters. Default: 1.
- **mode** (*str*) – Residual (MODE\_RES) or objective function value (MODE\_FUN, default) computation mode.

**Returns result** – gradient, finite difference approximations and error estimates.

**Return type** pd.DataFrame

**check\_sensi\_orders** (*sensi\_orders, mode*)

Check if the objective is able to compute the requested sensitivities. If not, throw an exception.

**finalize\_history** ()

Finalize the history object.

**get\_fval** (*x*)

Get the function value at x.

**get\_grad** (*x*)

Get the gradient at x.

**get\_hess** (*x*)

Get the Hessian at x.

**get\_res** (*x*)

Get the residuals at x.

**get\_sres** (*x*)

Get the residual sensitivities at x.

**has\_fun**

**has\_grad**

**has\_hess**

**has\_hessp**

**has\_res**

**has\_sres**

**static output\_to\_dict** (*sensi\_orders, mode, output\_tuple*)

Convert output tuple to dict.

**static output\_to\_tuple** (*sensi\_orders, mode, \*\*kwargs*)

Return values as requested by the caller, since usually only a subset is demanded. One output is returned as-is, more than one output are returned as a tuple in order (fval, grad, hess).

**reset** ()

Completely reset the objective, i.e. undo the modifications in `update_from_problem()`.

**reset\_history** (*index=None*)

Reset the objective history and specify temporary saving options.

**Parameters** *index* (As in `ObjectiveHistory.index`.) –

**update\_from\_problem** (*dim\_full, x\_free\_indices, x\_fixed\_indices, x\_fixed\_vals*)

Handle fixed parameters. Later, the objective will be given parameter vectors *x* of dimension *dim*, which have to be filled up with fixed parameter values to form a vector of dimension *dim\_full*  $\geq$  *dim*. This vector is then used to compute function value and derivatives. The derivatives must later be reduced again to dimension *dim*.

This is so as to make the fixing of parameters transparent to the caller.

The methods `preprocess`, `postprocess` are overwritten for the above functionality, respectively.

#### Parameters

- **dim\_full** (*int*) – Dimension of the full vector including fixed parameters.
- **x\_free\_indices** (*array\_like of int*) – Vector containing the indices (zero-based) of free parameters (complimentary to *x\_fixed\_indices*).
- **x\_fixed\_indices** (*array\_like of int, optional*) – Vector containing the indices (zero-based) of parameter components that are not to be optimized.
- **x\_fixed\_vals** (*array\_like, optional*) – Vector of the same length as *x\_fixed\_indices*, containing the values of the fixed parameters.

```
class pypesto.objective.ObjectiveOptions (trace_record=False, trace_record_grad=True,
                                          trace_record_hess=False,
                                          trace_record_res=False,
                                          trace_record_sres=False,
                                          trace_record_chi2=True,
                                          trace_record_schi2=True, trace_all=True,
                                          trace_file=None, trace_save_iter=10)
```

Bases: dict

Options for the objective that are used in optimization, profiles and sampling.

#### Parameters

- **trace\_record** (*bool, optional*) – Flag indicating whether to record the trace of function calls. The `trace_record_*` flags only become effective if `trace_record` is True. Default: False.
- **trace\_record\_grad** (*bool, optional*) – Flag indicating whether to record the gradient in the trace. Default: True.
- **trace\_record\_hess** (*bool, optional*) – Flag indicating whether to record the Hessian in the trace. Default: False.
- **trace\_record\_res** (*bool, optional*) – Flag indicating whether to record the residual in the trace. Default: False.



- **trace\_record\_sres** (*bool, optional*) – Flag indicating whether to record the residual sensitivities in the trace. Default: False.
- **trace\_record\_chi2** (*bool, optional*) – Flag indicating whether to record the chi2 in the trace. Default: True.
- **trace\_record\_schi2** (*bool, optional*) – Flag indicating whether to record the chi2 sensitivities in the trace. Default: True.
- **trace\_all** (*bool, optional*) – Flag indicating whether to record all (True, default) or only better (False) values.
- **trace\_file** (*str or True, optional*) – Either pass a string here denoting the file name for storing the trace, or True, in which case the default file name “tmp\_trace\_{index}.dat” is used. A contained substring {index} is converted to the multistart index. Default: None, i.e. no file is created.
- **index, optional** (*trace\_save\_iter*.) – Trace is saved every *tr\_save\_iter* iterations. Default: 10.

```
__init__(trace_record=False,          trace_record_grad=True,          trace_record_hess=False,
         trace_record_res=False,      trace_record_sres=False,      trace_record_chi2=True,
         trace_record_schi2=True, trace_all=True, trace_file=None, trace_save_iter=10)
Initialize self. See help(type(self)) for accurate signature.
```

**static assert\_instance** (*maybe\_options*)  
Returns a valid options object.

**Parameters** *maybe\_options* (*ObjectiveOptions* or *dict*) –

`pypesto.objective.res_to_chi2` (*res*)

We assume that the residuals *res* are related to an objective function value *fval* = *chi2* via:

```
fval = 0.5 * sum(res**2)
```

which is the ‘Linear’ formulation in scipy.

`pypesto.objective.sres_to_schi2` (*res, sres*)

In line with the assumptions in `res_to_chi2`.

**class** `pypesto.objective.AmiciObjective`

Bases: `pypesto.objective.objective.Objective`

This class allows to create an objective directly from an amici model.

**\_\_init\_\_** ()  
Constructor.

**Parameters**

- **amici\_model** – The amici model.
- **amici\_solver** – The solver to use for the numeric integration of the model.
- **edatas** – The experimental data. If a list is passed, its entries correspond to multiple experimental conditions.
- **max\_sensi\_order** – Maximum sensitivity order supported by the model. Defaults to 2 if the model was compiled with `o2mode`, otherwise 1.
- **x\_ids** – Ids of optimization parameters. In the simplest case, this will be the AMICI model parameters (default).
- **x\_names** – Names of optimization parameters.

- **parameter\_mapping** – Mapping of optimization parameters to model parameters. Format as created by `amici.petab_objective.create_parameter_mapping`. The default is just to assume that optimization and simulation parameters coincide.
- **guess\_steadystate** – Whether to guess steadystates based on previous steadystates and respective derivatives. This option may lead to unexpected results for models with conservation laws and should accordingly be deactivated for those models.
- **n\_threads** – Number of threads that are used for parallelization over experimental conditions. If amici was not installed with openMP support this option will have no effect.
- **options** (`pypesto.ObjectiveOptions`, *optional*) – Further options.

**apply\_steadystate\_guess** (*condition\_ix*, *x\_dct*)

Use the stored steadystate as well as the respective sensitivity ( if available) and parameter value to approximate the steadystate at the current parameters using a zeroth or first order taylor approximation:  $x_{ss}(x') = x_{ss}(x) [+ dx_{ss}/dx(x)*(x'-x)]$

**get\_bound\_fun** ()

Generate a fun function that calls `_call_amici` with `MODE_FUN`. Defining a non-class function that references self as a local variable will bind the function to a copy of the current self object and will accordingly not take future changes to self into account.

**get\_bound\_res** ()

Generate a res function that calls `_call_amici` with `MODE_RES`. Defining a non-class function that references self as a local variable will bind the function to a copy of the current self object and will accordingly not take future changes to self into account.

**get\_error\_output** (*rdatas*)

Default output upon error.

**par\_arr\_to\_dct** (*x*: *List[float]*) → *Dict[str, float]*

Create dict from parameter vector.

**rebind\_fun** ()

Replace the current fun function with one that is bound to the current instance

**rebind\_res** ()

Replace the current res function with one that is bound to the current instance

**reset** ()

Resets the objective, including steadystate guesses

**reset\_steadystate\_guesses** ()

Resets all steadystate guess data

**store\_steadystate\_guess** (*condition\_ix*, *x\_dct*, *rdata*)

Store condition parameter, steadystate and steadystate sensitivity in `steadystate_guesses` if steadystate guesses are enabled for this condition

**class** `pypesto.objective.AggregatedObjective` (*objectives*, *x\_names=None*, *options=None*)

Bases: `pypesto.objective.objective.Objective`

This class allows to create an `aggregateObjective` from a list of `Objective` instances.

**\_\_init\_\_** (*objectives*, *x\_names=None*, *options=None*)

Constructor.

Parameters **objectives** (*list*) – List of `pypesto.objective` instances

**aggregate\_fun** (*x*)

**aggregate\_fun\_sensi\_orders** (*x*, *sensi\_orders*)

**aggregate\_grad**(*x*)

**aggregate\_hess**(*x*)

**aggregate\_hessp**(*x*)

**aggregate\_res**(*x*)

**aggregate\_res\_sensi\_orders**(*x*, *sensi\_orders*)

**aggregate\_sres**(*x*)

**reset\_steadystate\_guesses**()

Propagates `reset_steadystate_guesses()` to child objectives if available (currently only applies for amici objective)

**class** `pypesto.objective.PetabImporter`(*petab\_problem*: *petab.Problem*, *output\_folder*: *str* = *None*, *model\_name*: *str* = *None*)

Bases: `object`

**MODEL\_BASE\_DIR** = `'amici_models'`

**\_\_init\_\_**(*petab\_problem*: *petab.Problem*, *output\_folder*: *str* = *None*, *model\_name*: *str* = *None*)

**petab\_problem**: *petab.Problem* Managing access to the model and data.

**output\_folder**: *str*, optional Folder to contain the amici model. Defaults to `'./amici_models/model_name'`.

**model\_name**: *str*, optional Name of the model, which will in particular be the name of the compiled model python module.

**compile\_model**(*\*\*kwargs*)

Compile the model. If the output folder exists already, it is first deleted.

**Parameters** *kwargs* (Extra arguments passed to `amici.SbmlImporter.sbml2amici`) –

**create\_edatas**(*model*: *amici.Model* = *None*, *simulation\_conditions*=*None*) → `List[amici.ExpData]`

Create list of `amici.ExpData` objects.

**create\_model**(*force\_compile*=*False*, *\*args*, *\*\*kwargs*) → *amici.Model*

Import amici model. If necessary or *force\_compile* is `True`, compile first.

**Parameters**

- **force\_compile** (*str*, *optional*) – If `False`, the model is compiled only if the output folder does not exist yet. If `True`, the output folder is deleted and the model (re-)compiled in either case.

**Warning:** If *force\_compile*, then an existing folder of that name will be deleted.

- **kwargs** (*args*,) –

**create\_objective**(*model*=*None*, *solver*=*None*, *edatas*=*None*, *force\_compile*: *bool* = *False*)

Create a `pypesto.PetabAmiciObjective`.

**create\_problem**(*objective*)

**create\_solver**(*model*=*None*)

Return model solver.

**static from\_folder**(*folder*, *output\_folder*: *str* = *None*, *model\_name*: *str* = *None*)

Simplified constructor exploiting the standardized petab folder structure.

**Parameters**

- **folder** (*str*) – Path to the base folder of the model, as in `petab.Problem.from_folder`.
- **output\_folder** (*See `__init__`.*) –
- **model\_name** (*See `__init__`.*) –

**static from\_yaml** (*yaml\_config: Union[dict, str], output\_folder: str = None, model\_name: str = None*) → `pypesto.objective.petab_import.PetabImporter`  
Simplified constructor using a petab yaml file.

**rdatas\_to\_measurement\_df** (*rdatas, model=None*) → `pandas.core.frame.DataFrame`  
Create a measurement dataframe in the petab format from the passed *rdatas* and own information.

**Parameters rdatas** (*list of amici.RData*) – A list of *rdatas* as produced by `pypesto.AmiciObjective.__call__(x, return_dict=True)['rdatas']`.

**Returns df** – A dataframe built from the *rdatas* in the format as in `self.petab_problem.measurement_df`.

**Return type** `pandas.DataFrame`

## Problem

A problem contains the objective as well as all information like prior describing the problem to be solved.

```
class pypesto.problem.Problem(objective:          pypesto.objective.objective.Objective,      lb:
                                numpy.ndarray, ub:  numpy.ndarray, dim_full: Optional[int]
                                = None, x_fixed_indices: Optional[Iterable[int]] = None,
                                x_fixed_vals: Optional[Iterable[float]] = None, x_guesses: Op-
                                tional[Iterable[float]] = None, x_names: Optional[Iterable[str]]
                                = None)
```

Bases: object

The problem formulation. A problem specifies the objective function, boundaries and constraints, parameter guesses as well as the parameters which are to be optimized.

### Parameters

- **objective** (*pypesto.Objective*) – The objective function for minimization. Note that a shallow copy is created.
- **ub** (*lb,*) – The lower and upper bounds. For unbounded directions set to inf.
- **dim\_full** (*int, optional*) – The full dimension of the problem, including fixed parameters.
- **x\_fixed\_indices** (*array\_like of int, optional*) – Vector containing the indices (zero-based) of parameter components that are not to be optimized.
- **x\_fixed\_vals** (*array\_like, optional*) – Vector of the same length as *x\_fixed\_indices*, containing the values of the fixed parameters.
- **x\_guesses** (*array\_like, optional*) – Guesses for the parameter values, shape (g, dim), where g denotes the number of guesses. These are used as start points in the optimization.
- **x\_names** (*array\_like of str, optional*) – Parameter names that can be optionally used e.g. in visualizations. If *objective.get\_x\_names()* is not None, those values are used, else the values specified here are used if not None, otherwise the variable names are set to ['x0', ... 'x{dim\_full}']. The list must always be of length *dim\_full*.

**dim**

The number of non-fixed parameters. Computed from the other values.

**x\_free\_indices**

Vector containing the indices (zero-based) of free parameters (complimentary to x\_fixed\_indices).

**Type** array\_like of int

## Notes

On the fixing of parameter values:

The number of parameters dim\_full the objective takes as input must be known, so it must be either lb a vector of that size, or dim\_full specified as a parameter.

All vectors are mapped to the reduced space of dimension dim in \_\_init\_\_, regardless of whether they were in dimension dim or dim\_full before. If the full representation is needed, the methods get\_full\_vector() and get\_full\_matrix() can be used.

**\_\_init\_\_** (*objective: pypesto.objective.objective.Objective, lb: numpy.ndarray, ub: numpy.ndarray, dim\_full: Optional[int] = None, x\_fixed\_indices: Optional[Iterable[int]] = None, x\_fixed\_vals: Optional[Iterable[float]] = None, x\_guesses: Optional[Iterable[float]] = None, x\_names: Optional[Iterable[str]] = None*)  
Initialize self. See help(type(self)) for accurate signature.

**fix\_parameters** (*parameter\_indices, parameter\_vals*)

Fix specified parameters to specified values

**get\_full\_matrix** (*x*)

Map matrix from dim to dim\_full. Usually used for hessian.

**Parameters** *x* (*array\_like, shape=(dim, dim)*) – The matrix in dimension dim.

**get\_full\_vector** (*x, x\_fixed\_vals=None*)

Map vector from dim to dim\_full. Usually used for x, grad.

**Parameters**

- *x* (*array\_like, shape=(dim,)*) – The vector in dimension dim.
- *x\_fixed\_vals* (*array\_like, ndim=1, optional*) – The values to be used for the fixed indices. If None, then nans are inserted. Usually, None will be used for grad and problem.x\_fixed\_vals for x.

**get\_reduced\_matrix** (*x\_full*)

Map matrix from dim\_full to dim, i.e. delete fixed indices.

**Parameters** *x* (*array\_like, ndim=2*) – The matrix in dimension dim\_full.

**get\_reduced\_vector** (*x\_full*)

Map vector from dim\_full to dim, i.e. delete fixed indices.

**Parameters** *x* (*array\_like, ndim=1*) – The vector in dimension dim\_full.

**normalize\_input** (*check\_x\_guesses=True*)

Reduce all vectors to dimension dim and have the objective accept vectors of dimension dim.

**print\_parameter\_summary** ()

Prints a summary of what parameters are being optimized and what parameter boundaries are

**unfix\_parameters** (*parameter\_indices*)

Free specified parameters

`pypesto.optimize.minimize` (*problem*, *optimizer=None*, *n\_starts=100*, *startpoint\_method=None*, *result=None*, *engine=None*, *options=None*) → `pypesto.result.Result`

This is the main function to call to do multistart optimization.

### Parameters

- **problem** (`pypesto.Problem`) – The problem to be solved.
- **optimizer** (`pypesto.Optimizer`) – The optimizer to be used *n\_starts* times.
- **n\_starts** (`int`) – Number of starts of the optimizer.
- **startpoint\_method** (`{callable, False}`, *optional*) – Method for how to choose start points. `False` means the optimizer does not require start points, e.g. ‘pso’ method in ‘GlobalOptimizer’
- **result** (`pypesto.Result`) – A result object to append the optimization results to. For example, one might append more runs to a previous optimization. If `None`, a new object is created.
- **options** (`pypesto.OptimizeOptions`, *optional*) – Various options applied to the multistart optimization.

**class** `pypesto.optimize.OptimizeOptions` (*startpoint\_resample=False*, *allow\_failed\_starts=False*)

Bases: `dict`

Options for the multistart optimization.

### Parameters

- **startpoint\_resample** (`bool`, *optional*) – Flag indicating whether initial points are supposed to be resampled if function evaluation fails at the initial point
- **allow\_failed\_starts** (`bool`, *optional*) – Flag indicating whether we tolerate that exceptions are thrown during the minimization process.

**\_\_init\_\_** (*startpoint\_resample=False*, *allow\_failed\_starts=False*)

Initialize self. See `help(type(self))` for accurate signature.

**static assert\_instance** (*maybe\_options*)

Returns a valid options object.

Parameters **maybe\_options** (`OptimizeOptions` or `dict`)-

```
class pypesto.optimize.OptimizerResult (x=None, fval=None, grad=None, hess=None,
                                         n_fval=None, n_grad=None, n_hess=None,
                                         n_res=None, n_sres=None, x0=None, fval0=None,
                                         trace=None, exitflag=None, time=None, mes-
                                         sage=None)
```

Bases: `dict`

The result of an optimizer run. Used as a standardized return value to map from the individual result objects returned by the employed optimizers to the format understood by pypesto.

Can be used like a dict.

**x**

The best found parameters.

**Type** ndarray

**fval**

The best found function value, `fun(x)`.

**Type** float

**grad, hess**

The gradient and Hessian at `x`.

**Type** ndarray

**n\_fval**

Number of function evaluations.

**Type** int

**n\_grad**

Number of gradient evaluations.

**Type** int

**n\_hess**

Number of Hessian evaluations.

**Type** int

**exitflag**

The exitflag of the optimizer.

**Type** int

**message**

Textual comment on the optimization result.

**Type** str

## Notes

Any field not supported by the optimizer is filled with `None`. Some fields are filled by pypesto itself.



```
__init__(x=None, fval=None, grad=None, hess=None, n_fval=None, n_grad=None, n_hess=None,
         n_res=None, n_sres=None, x0=None, fval0=None, trace=None, exitflag=None, time=None,
         message=None)
```

Initialize self. See help(type(self)) for accurate signature.

**class** pypesto.optimize.**Optimizer**

Bases: abc.ABC

This is the optimizer base class, not functional on its own.

An optimizer takes a problem, and possibly a start point, and then performs an optimization. It returns an `OptimizerResult`.

```
__init__()
```

Default constructor.

```
static get_default_options()
```

Create default options specific for the optimizer.

```
is_least_squares()
```

```
minimize(problem, x0, index)
```

**class** pypesto.optimize.**ScipyOptimizer**(method='L-BFGS-B', tol=1e-09, options=None)

Bases: pypesto.optimize.optimizer.Optimizer

Use the SciPy optimizers.

```
__init__(method='L-BFGS-B', tol=1e-09, options=None)
```

Default constructor.

```
static get_default_options()
```

Create default options specific for the optimizer.

```
is_least_squares()
```

```
minimize(problem, x0, index)
```

**class** pypesto.optimize.**DlibOptimizer**(method, options=None)

Bases: pypesto.optimize.optimizer.Optimizer

Use the Dlib toolbox for optimization.

```
__init__(method, options=None)
```

Default constructor.

```
static get_default_options()
```

Create default options specific for the optimizer.

```
is_least_squares()
```

```
minimize(problem, x0, index)
```

**class** pypesto.optimize.**GlobalOptimizer**(method='pso', options=None)

Bases: pypesto.optimize.optimizer.Optimizer

```
__init__(method='pso', options=None)
```

Default constructor.

```
is_least_squares()
```

```
minimize(problem, x0, index)
```



`pypesto.profile.parameter_profile` (*problem*, *result*, *optimizer*, *profile\_index=None*, *profile\_list=None*, *result\_index=0*, *next\_guess\_method=None*, *profile\_options=None*) → `pypesto.result.Result`

This is the main function to call to do parameter profiling.

### Parameters

- **problem** (`pypesto.Problem`) – The problem to be solved.
- **result** (`pypesto.Result`) – A result object to initialize profiling and to append the profiling results to. For example, one might append more profiling runs to a previous profile, in order to merge these. The existence of an optimization result is obligatory.
- **optimizer** (`pypesto.Optimizer`) – The optimizer to be used along each profile.
- **profile\_index** (*ndarray of integers, optional*) – array with parameter indices, whether a profile should be computed (1) or not (0) Default is all profiles should be computed
- **profile\_list** (*integer, optional*) – integer which specifies whether a call to the profiler should create a new list of profiles (default) or should be added to a specific profile list
- **result\_index** (*integer, optional*) – index from which optimization result profiling should be started (default: global optimum, i.e., index = 0)
- **next\_guess\_method** (*callable, optional*) – function handle to a method that creates the next starting point for optimization in profiling.
- **profile\_options** (`pypesto.ProfileOptions`, *optional*) – Various options applied to the profile optimization.

```
class pypesto.profile.ProfileOptions (default_step_size=0.01,          min_step_size=0.001,
                                     max_step_size=1.0,             step_size_factor=1.25,
                                     delta_ratio_max=0.1,           ratio_min=0.145,
                                     reg_points=10,                 reg_order=4,
                                     magic_factor_obj_value=0.5)
```

Bases: dict

Options for optimization based profiling.

#### Parameters

- **default\_step\_size** (*float, optional*) – default step size of the profiling routine along the profile path (adaptive step lengths algorithms will only use this as a first guess and then refine the update)
- **min\_step\_size** (*float, optional*) – lower bound for the step size in adaptive methods
- **max\_step\_size** (*float, optional*) – upper bound for the step size in adaptive methods
- **step\_size\_factor** (*float, optional*) – Adaptive methods recompute the likelihood at the predicted point and try to find a good step length by a sort of line search algorithm. This factor controls step handling in this line search
- **delta\_ratio\_max** (*float, optional*) – maximum allowed drop of the posterior ratio between two profile steps
- **ratio\_min** (*float, optional*) – lower bound for likelihood ratio of the profile, based on inverse chi2-distribution. The default corresponds to 95% confidence
- **reg\_points** (*float, optional*) – number of profile points used for regression in regression based adaptive profile points proposal
- **reg\_order** (*float, optional*) – maximum degree of regression polynomial used in regression based adaptive profile points proposal
- **magic\_factor\_obj\_value** (*float, optional*) – There is this magic factor in the old profiling code which slows down profiling at small ratios (must be  $\geq 0$  and  $< 1$ )

**\_\_init\_\_** (*default\_step\_size=0.01, min\_step\_size=0.001, max\_step\_size=1.0, step\_size\_factor=1.25, delta\_ratio\_max=0.1, ratio\_min=0.145, reg\_points=10, reg\_order=4, magic\_factor\_obj\_value=0.5*)

Initialize self. See help(type(self)) for accurate signature.

**static create\_instance** (*maybe\_options*)

Returns a valid options object.

Parameters **maybe\_options** (*ProfileOptions or dict*) –

**class** pypesto.profile.ProfilerResult (*x\_path, fval\_path, ratio\_path, gradnorm\_path=None, exitflag\_path=None, time\_path=None, time\_total=0.0, n\_fval=0, n\_grad=0, n\_hess=0, message=None*)

Bases: dict

The result of a profiler run. The standardized return value from pypesto.profile, which can either be initialized from an OptimizerResult or from an existing ProfilerResult (in order to extent the computation).

Can be used like a dict.

#### **x\_path**

The path of the best found parameters along the profile (Dimension:  $n_{\text{par}} \times n_{\text{profile\_points}}$ )

Type ndarray

#### **fval\_path**

The function values,  $\text{fun}(x)$ , along the profile.

Type ndarray

**ratio\_path**

The ratio of the posterior function along the profile.

**Type** ndarray

**gradnorm\_path**

The gradient norm along the profile.

**Type** ndarray

**exitflag\_path**

The exitflags of the optimizer along the profile.

**Type** ndarray

**time\_path**

The computation time of the optimizer runs along the profile.

**Type** ndarray

**time\_total**

The total computation time for the profile.

**Type** ndarray

**n\_fval**

Number of function evaluations.

**Type** int

**n\_grad**

Number of gradient evaluations.

**Type** int

**n\_hess**

Number of Hessian evaluations.

**Type** int

**message**

Textual comment on the profile result.

**Type** str

## Notes

Any field not supported by the profiler or the profiling optimizer is filled with None. Some fields are filled by pypesto itself.

**\_\_init\_\_** (*x\_path*, *fval\_path*, *ratio\_path*, *gradnorm\_path*=None, *exitflag\_path*=None, *time\_path*=None, *time\_total*=0.0, *n\_fval*=0, *n\_grad*=0, *n\_hess*=0, *message*=None)  
Initialize self. See help(type(self)) for accurate signature.

**append\_profile\_point** (*x*, *fval*, *ratio*, *gradnorm*=nan, *exitflag*=nan, *time*=nan, *n\_fval*=0, *n\_grad*=0, *n\_hess*=0)  
This function appends a new OptimizerResult to an existing ProfilerResults

**flip\_profile** ()

This function flips the profiling direction (left-right) Profiling direction needs to be changed once (if the profile is new) and twice, if we append to an existing profile



## CHAPTER 9

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Sample

---





The `pypesto.Result` object contains all results generated by the `pypesto` components. It contains sub-results for optimization, profiles, sampling.

**class** `pypesto.result.OptimizeResult`

Bases: `object`

Result of the `minimize()` function.

**\_\_init\_\_** ()

Initialize self. See `help(type(self))` for accurate signature.

**append** (*optimizer\_result*)

Append an optimizer result to the result object.

**Parameters** `optimizer_result` – The result of one (local) optimizer run.

**as\_dataframe** (*keys=None*) → `pandas.core.frame.DataFrame`

Get as pandas DataFrame. If `keys` is a list, return only the specified values.

**as\_list** (*keys=None*) → list

Get as list. If `keys` is a list, return only the specified values.

**Parameters** `keys` (*list(str), optional*) – Labels of the field to extract.

**get\_for\_key** (*key*) → list

Extract the list of values for the specified key as a list.

**sort** ()

Sort the optimizer results by function value `fval` (ascending).

**class** `pypesto.result.ProfileResult`

Bases: `object`

Result of the `profile()` function.

**\_\_init\_\_** ()

Initialize self. See `help(type(self))` for accurate signature.

**add\_profile** (*profiler\_result*, *i\_parameter*)

Writes a profiler result to the result object at *i\_parameter*.

**Parameters**

- **profiler\_result** – The result of one (local) profiler run.
- **i\_parameter** – integer specifying the parameter index

**create\_new\_profile** (*profiler\_result=None*)

Append an profiler result to the result object.

**Parameters**

- **profiler\_result** – The result of one (local) profiler run or None, if to be left empty
- **profile\_list** (*integer*) – index specifying the list of profiles, to which we want to append

**create\_new\_profile\_list** ()

Append an profiler result to the result object.

**get\_current\_profile** (*i\_parameter*)

Append an profiler result to the result object.

**Parameters** **i\_parameter** – integer specifying the profile index

**class** `pypesto.result.Result` (*problem=None*)

Bases: `object`

Universal result object for pypesto. The algorithms like optimize, profile, sample fill different parts of it.

**problem**

The problem underlying the results.

**Type** `pypesto.Problem`

**optimize\_result**

The results of the optimizer runs.

**profile\_result**

The results of the profiler run.

**sample\_result**

The results of the sampler run.

**\_\_init\_\_** (*problem=None*)

Initialize self. See `help(type(self))` for accurate signature.

**class** `pypesto.result.SampleResult`

Bases: `object`

Result of the `sample()` function.

**\_\_init\_\_** ()

Initialize self. See `help(type(self))` for accurate signature.

The execution of the multistarts can be parallelized in different ways, e.g. multi-threaded or cluster-based. Note that it is not checked whether a single multistart itself is parallelized.

```
class pypesto.engine.Engine
```

Bases: `abc.ABC`

Abstract engine base class.

```
__init__()
```

Initialize self. See `help(type(self))` for accurate signature.

```
execute(tasks: List)
```

```
class pypesto.engine.SingleCoreEngine
```

Bases: `pypesto.engine.base.Engine`

Dummy engine for sequential execution on one core. Note that the objective itself may be multithreaded.

```
__init__()
```

Initialize self. See `help(type(self))` for accurate signature.

```
execute(tasks)
```

Execute all tasks in a simple for loop sequentially.

```
class pypesto.engine.MultiProcessEngine(n_procs: int = None)
```

Bases: `pypesto.engine.base.Engine`

Parallelize the task execution using the *multiprocessing.Pool* environment.

```
n_procs
```

The number of cores to use. Defaults to the number of cpus available on the system according to `os.cpu_count()`. The effectively used number of cores will be the minimum of `n_procs` and the number of tasks submitted (and the number of CPUs available).

**Type** `int`, optional

```
__init__(n_procs: int = None)
```

Initialize self. See `help(type(self))` for accurate signature.

**execute** (*tasks*)

**class** pypesto.engine.**OptimizerTask**(*optimizer, problem, startpoint, j\_start, options, handle\_exception*)

Bases: pypesto.engine.task.Task

A multistart optimization task, performed in *pypesto.minimize*.

**\_\_init\_\_** (*optimizer, problem, startpoint, j\_start, options, handle\_exception*)

Create the task object.

#### Parameters

- **optimizer** (*the optimizer to use.*)–
- **problem** (*the problem to solve.*)–
- **startpoint** (*the point from which to start.*)–
- **j\_start** (*the index of the multistart.*)–
- **options** (*options object applying to optimization.*)–
- **handle\_exception** (*callable to apply when the optimization fails.*)–

**execute** ()

Execute the task and return its results.

pypesto comes with various visualization routines. To use these, import `pypesto.visualize`.

```
class pypesto.visualize.ReferencePoint (reference=None, x=None, fval=None, color=None,  
                                         legend=None)
```

Bases: dict

Reference point for plotting. Should contain a parameter value and an objective function value, may also contain a color and a legend.

Can be used like a dict.

**x**

Reference parameters.

**Type** ndarray

**fval**

Function value,  $\text{fun}(x)$ , for reference parameters.

**Type** float

**color**

Color which should be used for reference point.

**Type** RGBA, optional

**auto\_color**

flag indicating whether color for this reference point should be assigned automatically or whether it was assigned by user

**Type** boolean

**legend**

legend text for reference point

**Type** str

```
__init__ (reference=None, x=None, fval=None, color=None, legend=None)
```

Initialize self. See `help(type(self))` for accurate signature.

```
pypesto.visualize.create_references (references=None,          x=None,          fval=None,
                                     color=None,             legend=None) →
                                     List[pypesto.visualize.reference_points.ReferencePoint]
```

This function creates a list of reference point objects from user inputs

#### Parameters

- **references** (*ReferencePoint or dict or list, optional*) – Will be converted into a list of RefPoints
- **x** (*ndarray, optional*) – Parameter vector which should be used for reference point
- **fval** (*float, optional*) – Objective function value which should be used for reference point
- **color** (*RGBA, optional*) – Color which should be used for reference point.
- **legend** (*str*) – legend text for reference point

**Returns** **colors** – One for each element in ‘vals’.

**Return type** list of RGBA

```
pypesto.visualize.assign_clusters (vals)
```

Find clustering.

**Parameters** **vals** (*numeric list or array*) – List to be clustered.

#### Returns

- **clust** (*numeric list*) – Indicating the corresponding cluster of each element from ‘vals’.
- **clustsize** (*numeric list*) – Size of clusters, length equals number of clusters.

```
pypesto.visualize.assign_clustered_colors (vals,          balance_alpha=True,          high-
                                           light_global=True)
```

Cluster and assign colors.

#### Parameters

- **vals** (*numeric list or array*) – List to be clustered and assigned colors.
- **balance\_alpha** (*bool (optional)*) – Flag indicating whether alpha for large clusters should be reduced to avoid overplotting (default: True)
- **highlight\_global** (*bool (optional)*) – flag indicating whether global optimum should be highlighted

**Returns** **colors** – One for each element in ‘vals’.

**Return type** list of RGBA

```
pypesto.visualize.assign_colors (vals,          colors=None,          balance_alpha=True,          high-
                                light_global=True)
```

Assign colors or format user specified colors.

#### Parameters

- **vals** (*numeric list or array*) – List to be clustered and assigned colors.
- **colors** (*list, or RGBA, optional*) – list of colors, or single color
- **balance\_alpha** (*bool (optional)*) – Flag indicating whether alpha for large clusters should be reduced to avoid overplotting (default: True)
- **highlight\_global** (*bool (optional)*) – flag indicating whether global optimum should be highlighted

**Returns** **colors** – One for each element in ‘vals’.

**Return type** list of RGBA

`pypesto.visualize.process_result_list(results, colors=None, legends=None)`  
 assigns colors and legends to a list of results, chekc user provided lists

#### Parameters

- **results** (*list or pypesto.Result*) – list of pypesto.Result objects or a single pypesto.Result
- **colors** (*list, optional*) – list of RGBA colors
- **legends** (*str or list*) – labels for line plots

#### Returns

- **results** (*list of pypesto.Result*) – list of pypesto.Result objects
- **colors** (*list of RGBA*) – One for each element in ‘results’.
- **legends** (*list of str*) – labels for line plots

`pypesto.visualize.process_offset_y(offset_y: Optional[float], scale_y: str, min_val: float) → float`  
 compute offset for y-axis, depend on user settings

#### Parameters

- **offset\_y** – value for offsetting the later plotted values, in order to ensure positivity if a semilog-plot is used
- **scale\_y** – Can be ‘lin’ or ‘log10’, specifying whether values should be plotted on linear or on log10-scale
- **min\_val** – Smallest value to be plotted

**Returns** **offset\_y** – value for offsetting the later plotted values, in order to ensure positivity if a semilog-plot is used

**Return type** float

`pypesto.visualize.process_y_limits(ax, y_limits)`  
 apply user specified limits of y-axis

#### Parameters

- **ax** (*matplotlib.Axes, optional*) – Axes object to use.
- **y\_limits** (*ndarray*) – y\_limits, minimum and maximum, for current axes object
- **min\_val** (*float*) – Smallest value to be plotted

**Returns** **ax** – Axes object to use.

**Return type** matplotlib.Axes, optional

`pypesto.visualize.waterfall(results, ax=None, size=(18.5, 10.5), y_limits=None, scale_y='log10', offset_y=None, start_indices=None, reference=None, colors=None, legends=None)`

Plot waterfall plot.

#### Parameters

- **results** (*pypesto.Result or list*) – Optimization result obtained by ‘optimize.py’ or list of those

- **ax** (*matplotlib.Axes, optional*) – Axes object to use.
- **size** (*tuple, optional*) – Figure size (width, height) in inches. Is only applied when no ax object is specified
- **y\_limits** (*float or ndarray, optional*) – maximum value to be plotted on the y-axis, or y-limits
- **scale\_y** (*str, optional*) – May be logarithmic or linear ('log10' or 'lin')
- **offset\_y** – offset for the y-axis, if it is supposed to be in log10-scale
- **start\_indices** (*list or int*) – list of integers specifying the multistart to be plotted or int specifying up to which start index should be plotted
- **reference** (*list, optional*) – List of reference points for optimization results, containing at least a function value fval
- **colors** (*list, or RGBA, optional*) – list of colors, or single color or list of colors for plotting. If not set, clustering is done and colors are assigned automatically
- **legends** (*list or str*) – Labels for line plots, one label per result object

**Returns** **ax** – The plot axes.

**Return type** matplotlib.Axes

```
pypesto.visualize.waterfall_lowlevel(fvals, scale_y='log10', offset_y=0.0, ax=None,
                                     size=(18.5, 10.5), colors=None, legend_text=None)
```

Plot waterfall plot using list of function values.

#### Parameters

- **fvals** (*numeric list or array*) – Including values need to be plotted.
- **scale\_y** (*str, optional*) – May be logarithmic or linear ('log10' or 'lin')
- **offset\_y** – offset for the y-axis, if it is supposed to be in log10-scale
- **ax** (*matplotlib.Axes, optional*) – Axes object to use.
- **size** (*tuple, optional*) – see waterfall
- **colors** (*list, or RGBA, optional*) – list of colors, or single color or list of colors for plotting. If not set, clustering is done and colors are assigned automatically
- **legend\_text** (*str*) – Label for line plots

**Returns** **ax** – The plot axes.

**Return type** matplotlib.Axes

```
pypesto.visualize.parameters(results, ax=None, free_indices_only=True, lb=None, ub=None,
                             size=None, reference=None, colors=None, legends=None, balance_alpha=True, start_indices=None)
```

Plot parameter values.

#### Parameters

- **results** (*pypesto.Result or list*) – Optimization result obtained by 'optimize.py' or list of those
- **ax** (*matplotlib.Axes, optional*) – Axes object to use.
- **free\_indices\_only** (*bool, optional*) – If True, only free parameters are shown. If False, also the fixed parameters are shown.



- **ub** (*lb*,) – If not None, override result.problem.lb, problem.problem.ub. Dimension either result.problem.dim or result.problem.dim\_full.
- **size** (*tuple*, *optional*) – Figure size (width, height) in inches. Is only applied when no ax object is specified
- **reference** (*list*, *optional*) – List of reference points for optimization results, containing at least a function value fval
- **colors** (*list*, *or RGBA*, *optional*) – list of colors, or single color color or list of colors for plotting. If not set, clustering is done and colors are assigned automatically
- **legends** (*list or str*) – Labels for line plots, one label per result object
- **balance\_alpha** (*bool (optional)*) – Flag indicating whether alpha for large clusters should be reduced to avoid overplotting (default: True)
- **start\_indices** (*list or int*) – list of integers specifying the multistarts to be plotted or int specifying up to which start index should be plotted

**Returns** **ax** – The plot axes.

**Return type** matplotlib.Axes

```
pypesto.visualize.parameters_lowlevel(xs, fvals, lb=None, ub=None, x_labels=None,
                                     ax=None, size=None, colors=None, linestyle='-',
                                     legend_text=None, balance_alpha=True)
```

Plot parameters plot using list of parameters.

#### Parameters

- **xs** (*nested list or array*) – Including optimized parameters for each startpoint. Shape: (n\_starts, dim).
- **fvals** (*numeric list or array*) – Function values. Needed to assign cluster colors.
- **ub** (*lb*,) – The lower and upper bounds.
- **x\_labels** (*array\_like of str, optional*) – Labels to be used for the parameters.
- **ax** (*matplotlib.Axes, optional*) – Axes object to use.
- **size** (*tuple, optional*) – see parameters
- **colors** (*list of RGBA*) – One for each element in 'fvals'.
- **linestyle** (*str, optional*) – linestyle argument for parameter plot
- **legend\_text** (*str*) – Label for line plots
- **balance\_alpha** (*bool (optional)*) – Flag indicating whether alpha for large clusters should be reduced to avoid overplotting (default: True)

**Returns** **ax** – The plot axes.

**Return type** matplotlib.Axes

```
pypesto.visualize.optimizer_history(results, ax=None, size=(18.5, 10.5), trace_x='steps',
                                   trace_y='fval', scale_y='log10', offset_y=None,
                                   colors=None, y_limits=None, start_indices=None,
                                   reference=None, legends=None)
```

Plot history of optimizer. Can plot either the history of the cost function or of the gradient norm, over either the optimizer steps or the computation time.

**Parameters**

- **results** (*pypesto.Result* or *list*) – Optimization result obtained by ‘optimize.py’ or list of those
- **ax** (*matplotlib.Axes*, *optional*) – Axes object to use.
- **size** (*tuple*, *optional*) – Figure size (width, height) in inches. Is only applied when no ax object is specified
- **trace\_x** (*str*, *optional*) – What should be plotted on the x-axis? Possibilities: ‘time’, ‘steps’ Default: ‘steps’
- **trace\_y** (*str*, *optional*) – What should be plotted on the y-axis? Possibilities: ‘fval’, ‘gradnorm’, ‘stepsize’ Default: ‘fval’
- **scale\_y** (*str*, *optional*) – May be logarithmic or linear (‘log10’ or ‘lin’)
- **offset\_y** (*float*, *optional*) – Offset for the y-axis-values, as these are plotted on a log10-scale Will be computed automatically if necessary
- **colors** (*list*, or *RGBA*, *optional*) – list of colors, or single color color or list of colors for plotting. If not set, clustering is done and colors are assigned automatically
- **y\_limits** (*float* or *ndarray*, *optional*) – maximum value to be plotted on the y-axis, or y-limits
- **start\_indices** (*list* or *int*) – list of integers specifying the multistart to be plotted or int specifying up to which start index should be plotted
- **reference** (*list*, *optional*) – List of reference points for optimization results, containing et least a function value fval
- **legends** (*list* or *str*) – Labels for line plots, one label per result object

**Returns** **ax** – The plot axes.

**Return type** *matplotlib.Axes*

```
pypesto.visualize.optimizer_history_lowlevel (vals,          scale_y='log10',          col-  
                                             ors=None,      ax=None,      size=(18.5,  
10.5),      x_label='Optimizer  steps',  
y_label='Objective      value',      leg-  
end_text=None)
```

Plot optimizer history using list of numpy arrays.

**Parameters**

- **vals** (*list of numpy arrays*) – list of 2xn-arrays (x\_values and y\_values of the trace)
- **scale\_y** (*str*, *optional*) – May be logarithmic or linear (‘log10’ or ‘lin’)
- **colors** (*list*, or *RGBA*, *optional*) – list of colors, or single color color or list of colors for plotting. If not set, clustering is done and colors are assigned automatically
- **ax** (*matplotlib.Axes*, *optional*) – Axes object to use.
- **size** (*tuple*, *optional*) – see waterfall
- **x\_label** (*str*) – label for x-axis
- **y\_label** (*str*) – label for y-axis
- **legend\_text** (*str*) – Label for line plots

**Returns** **ax** – The plot axes.

**Return type** matplotlib.Axes

`pypesto.visualize.profiles` (*results*, *ax=None*, *profile\_indices=None*, *size=(18.5, 6.5)*, *reference=None*, *colors=None*, *legends=None*, *profile\_list\_id=0*)

Plot classical 1D profile plot (using the posterior, e.g. Gaussian like profile)

#### Parameters

- **results** (*list or pypesto.Result*) – list of `pypesto.Result` or single `pypesto.Result`
- **ax** (*list of matplotlib.Axes, optional*) – List of axes objects to use.
- **profile\_indices** (*list of integer values*) – list of integer values specifying which profiles should be plotted
- **size** (*tuple, optional*) – Figure size (width, height) in inches. Is only applied when no ax object is specified
- **reference** (*list, optional*) – List of reference points for optimization results, containing at least a function value `fval`
- **colors** (*list, or RGBA, optional*) – list of colors, or single color or list of colors for plotting. If not set, clustering is done and colors are assigned automatically
- **legends** (*list or str, optional*) – Labels for line plots, one label per result object
- **profile\_list\_id** (*int, optional*) – index of the profile list to be used for profiling

**Returns** **ax** – The plot axes.

**Return type** matplotlib.Axes

`pypesto.visualize.profiles_lowlevel` (*fvals*, *ax=None*, *size=(18.5, 6.5)*, *color=None*, *legend\_text=None*)

Lowlevel routine for profile plotting, working with a list of arrays only, opening different axes objects in case

#### Parameters

- **fvals** (*numeric list or array*) – Including values need to be plotted.
- **ax** (*list of matplotlib.Axes, optional*) – list of axes object to use.
- **size** (*tuple, optional*) – Figure size (width, height) in inches. Is only applied when no ax object is specified
- **size** – Figure size (width, height) in inches. Is only applied when no ax object is specified
- **color** (*RGBA, optional*) – color for profiles in plot.
- **legend\_text** (*str*) – Label for line plots

**Returns** **ax** – The plot axes.

**Return type** matplotlib.Axes

`pypesto.visualize.profile_lowlevel` (*fvals*, *ax=None*, *size=(18.5, 6.5)*, *color=None*, *legend\_text=None*)

Lowlevel routine for plotting one profile, working with a numpy array only

#### Parameters

- **fvals** (*numeric list or array*) – Including values need to be plotted.
- **ax** (*matplotlib.Axes, optional*) – Axes object to use.

- **size** (*tuple*, *optional*) – Figure size (width, height) in inches. Is only applied when no `ax` object is specified
- **color** (*RGBA*, *optional*) – color for profiles in plot.
- **legend\_text** (*str*) – Label for line plots

**Returns** `ax` – The plot axes.

**Return type** `matplotlib.Axes`

Method for selecting points that can be used as start points for multistart optimization. All methods have the form

```
method(**kwargs) -> startpoints
```

where the kwargs can/should include the following parameters, which are passed by pypesto:

**n\_starts: int** Number of points to generate.

**lb, ub: ndarray** Lower and upper bound, may for most methods not contain nan or inf values.

**x\_guesses: ndarray, shape=(g, dim), optional** Parameter guesses by the user, where g denotes the number of guesses. Note that these are only possibly taken as reference points to generate new start points (e.g. to maximize some distance) depending on the method, but regardless of g, there are always n\_starts points generated and returned.

**objective: pypesto.Objective, optional** The objective can be used to evaluate the goodness of start points.

**max\_n\_fval: int, optional** The maximum number of evaluations of the objective function allowed.

```
pypesto.startpoint.uniform(**kwargs)
```

Generate uniform points.

```
pypesto.startpoint.latin_hypercube(**kwargs)
```

Generate latin hypercube points.

```
pypesto.startpoint.assign_startpoints(n_starts, startpoint_method, problem, options)
```

Assign startpoints.



### 14.1 0.0 series

#### 14.1.1 0.0.11 (2020-03-17)

- Rewrite AmiciObjective and PetabAmiciObjective simulation routine to directly use amici.petab\_objective routines (#209, #219, #225).
- Implement petab test suite checks (#228).
- Various error fixes, in particular regarding PETab and visualization.
- Improve trace structure.
- Fix conversion between fval and chi2, fix FIM (all #223).

#### 14.1.2 0.0.10 (2019-12-04)

- Only compute FIM when sensitivities are available (#194).
- Fix documentation build (#197).
- Add support for pyswarm optimizer (#198).
- Run travis tests for documentation and notebooks only on pull requests (#199).

#### 14.1.3 0.0.9 (2019-10-11)

- Update to AMICI 0.10.13, fix API changes (#185).
- Start using PETab import from AMICI to be able to import constant species (#184, #185)
- Require PETab $\geq$ 0.0.0a16 (#183)

#### 14.1.4 0.0.8 (2019-09-01)

- Add logo (#178).
- Fix petab API changes (#179).
- Some minor bugfixes (#168).

#### 14.1.5 0.0.7 (2019-03-21)

- Support noise models in Petab and Amici.
- Minor Petab update bug fixes.

#### 14.1.6 0.0.6 (2019-03-13)

- Several minor error fixes, in particular on tests and steady state.

#### 14.1.7 0.0.5 (2019-03-11)

- Introduce AggregatedObjective to use multiple objectives at once.
- Estimate steady state in AmiciObjective.
- Check amici model build version in PetabImporter.
- Use Amici multithreading in AmiciObjective.
- Allow to sort multistarts by initial value.
- Show usage of visualization routines in notebooks.
- Various fixes, in particular to visualization.

#### 14.1.8 0.0.4 (2019-02-25)

- Implement multi process parallelization engine for optimization.
- Introduce PrePostProcessor to more reliably handle pre- and post-processing.
- Fix problems with simulating for multiple conditions.
- Add more visualization routines and options for those (colors, reference points, plotting of lists of result objects)

#### 14.1.9 0.0.3 (2019-01-30)

- Import amici models and the petab data format automatically using pypesto.PetabImporter.
- Basic profiling routines.



#### **14.1.10 0.0.2 (2018-10-18)**

- Fix parameter values
- Record trace of function values
- Amici objective to directly handle amici models

#### **14.1.11 0.0.1 (2018-07-25)**

- Basic framework and implementation of the optimization



## CHAPTER 15

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### Authors

---

This package was mainly developed by:

- Jan Hasenauer
- Yannik Schälte
- Fabian Fröhlich
- Daniel Weindl
- Paul Stapor
- Leonard Schmiester
- Dantong Wang
- Leonard Schmiester
- Caro Loos



## CHAPTER 16

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### Contact

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Discovered an error? Need help? Not sure if something works as intended? Please contact us!

- Yannik Schälte: [yannik.schaelte@gmail.com](mailto:yannik.schaelte@gmail.com)



# CHAPTER 17

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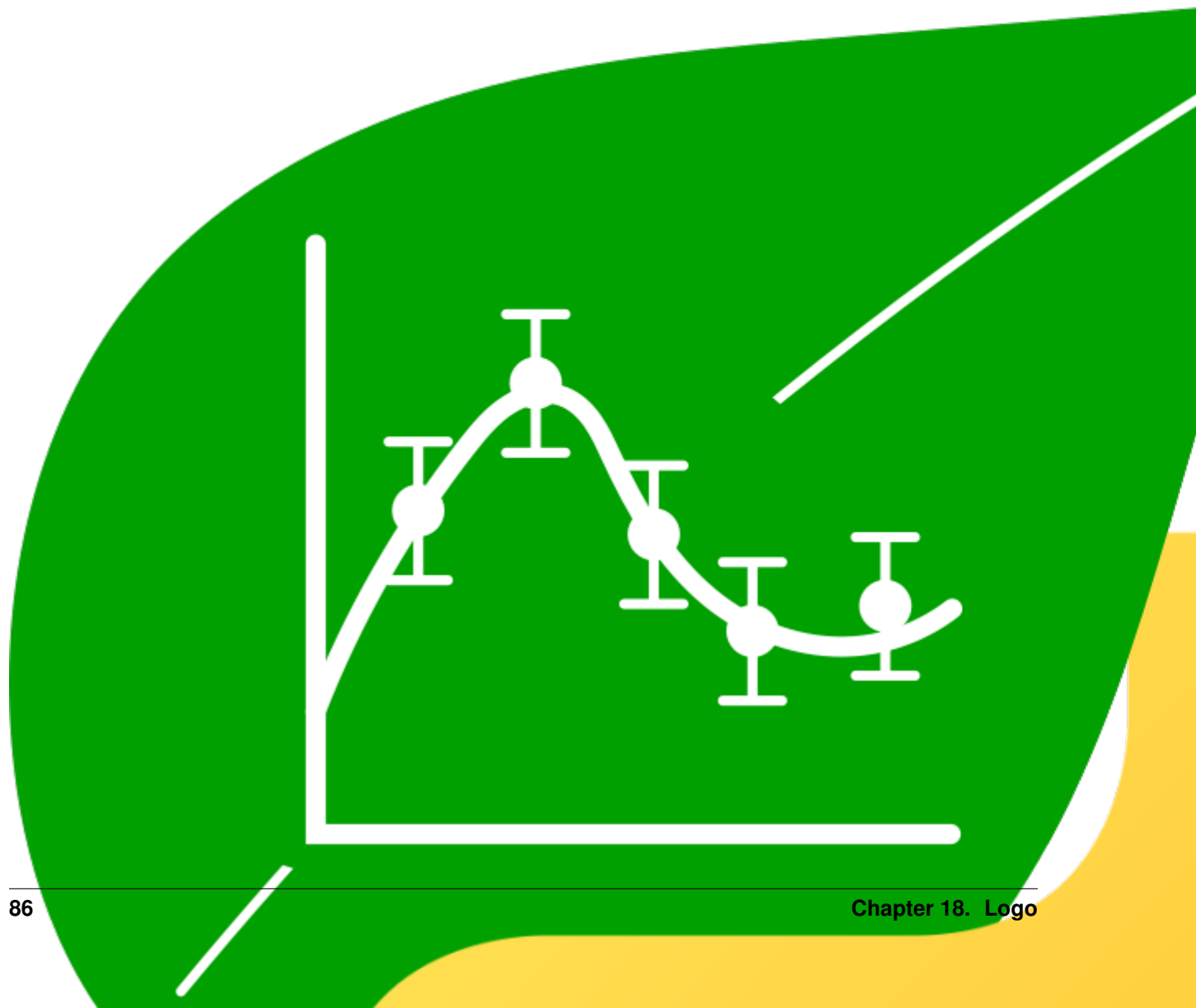


## CHAPTER 18

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Logo

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pyPESTO's logo can be found in multiple variants in the doc/logo directory on github, in svg and png format. It is made available under a [creative commons CC0 license](#). You are encouraged to use it e.g. in presentations and posters.

We thank Patrick Beart for his contribution to the logo.



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