Example to plot directly into latex

19-10-2019

1 Introduction

2 Genetic Algorithm Performance

To illustrate how the python code exports the figures directly into the report, this second "hw2" is included. Below are the pictures that are created by the code listed in **??** and **??**.

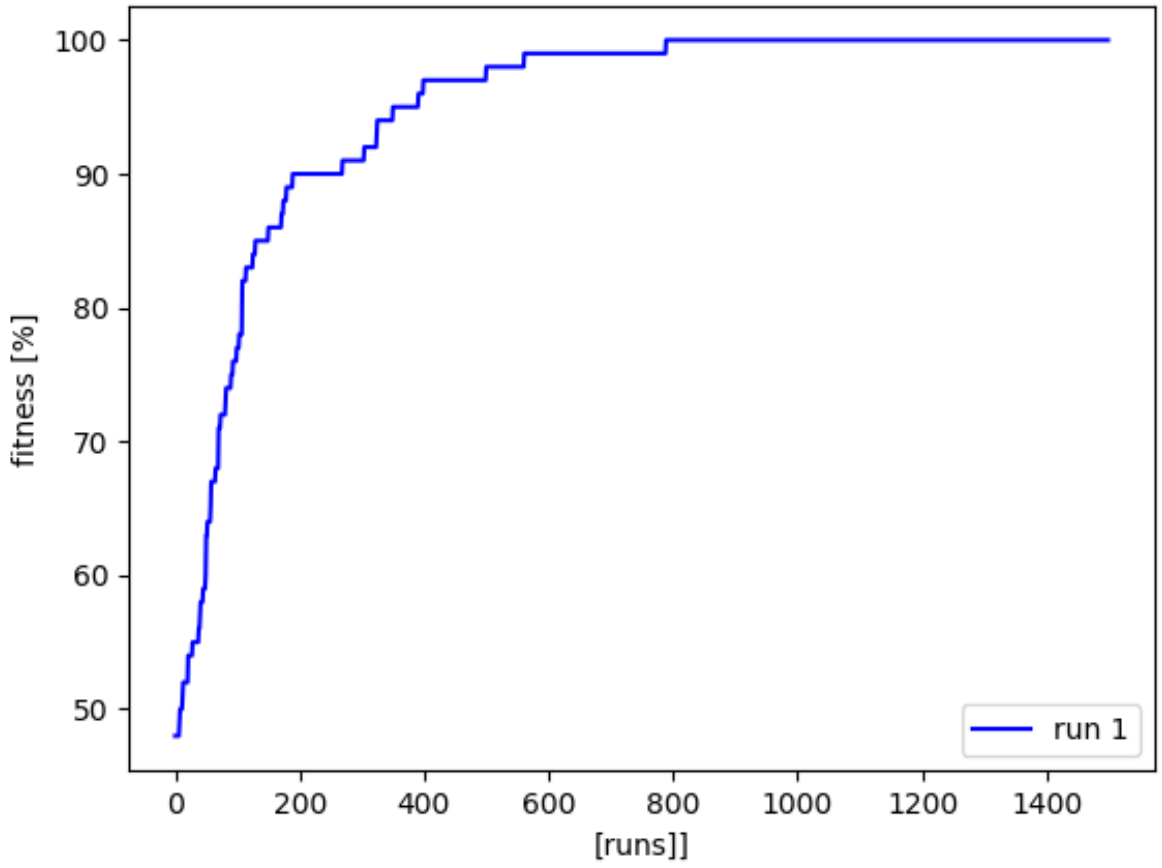


Figure 1: Performance of some genetic algorithm

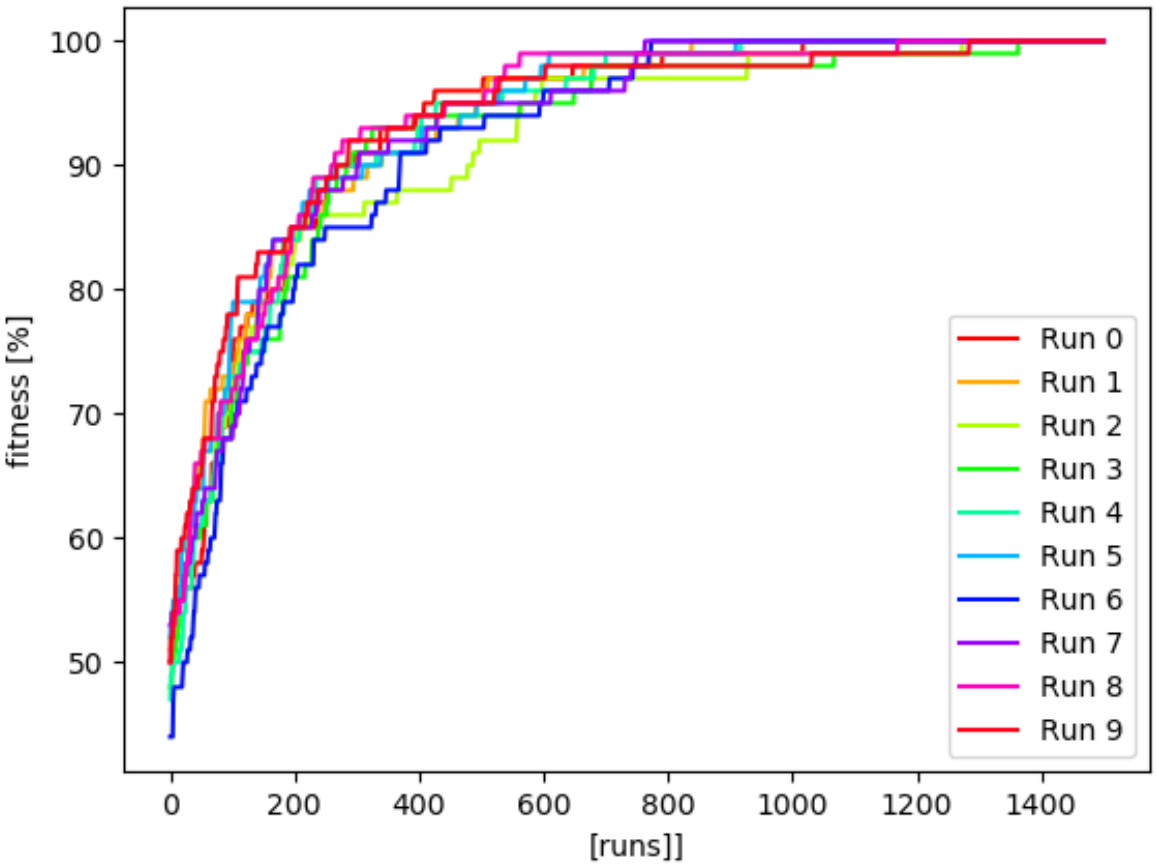


Figure 2: Performance of some genetic algorithm

A Appendix __main__.py

```
import os
from .Main import Main

print(f'Hi, I\'ll be running the main code, and I\'ll let you know
    ↪ when I\'m done.')
project_nr = 1
main = Main()

notebook_names = ['AE4868_example_notebook_update20201025.ipynb']
notebook_names = []# TODO: re-enable

# run the jupyter notebooks for assignment 1
main.run_jupyter_notebooks(project_nr,notebook_names)

# convert jupyter notebook for assignment 1 to pdf
main.convert_notebooks_to_pdf(project_nr,notebook_names)

# export the code to latex
main.export_code_to_latex(project_nr)

# compile the latex report
main.compile_latex_report(project_nr)

#################################################################
```

```
############example code to illustrate python-latex  image sync #########
###############runs arbitrary genetic algorithm, can be deleted ############
#################################################################
# run a genetic algorithm to create some data for a plot.
print("now running a")
res = main.do_run_a()

# plot some graph with a single line, general form is:
# plt_tex.plotSingleLines(plt_tex,x,y,"x-axis label","y-axis label", lineLabels,"filename",legend_position,project_nr)
# main.plt_tex.plotSingleLine(plt_tex,range(0, len(res)),res,"[runs ]]","fitness [%]","run 1","4a",4,project_nr)

# run a genetic algorithm to create some data for another plot.
print("now running b")
main.do4b(project_nr)

# run a genetic algorithm to create some data for another plot.
print("now running 4c")
main.do4c(project_nr)

print(f'Done.')
```

B Appendix Main.py

```python
# Example code that creates plots directly in report
# Code is an implementation of a genetic algorithm
import random
from matplotlib import pyplot as plt
from matplotlib import lines
import matplotlib.pyplot as plt
import numpy as np

from .Compile_latex import Compile_latex
from .Plot_to_tex import Plot_to_tex as plt_tex
from .Run_jupyter_notebooks import Run_jupyter_notebook
from .Export_code_to_latex import export_code_to_latex

# define global variables for genetic algorithm example
string_length = 100
mutation_chance= 1.0/string_length
max_iterations = 1500

class Main:

    def __init__(self):
        self.run_jupyter_notebook = Run_jupyter_notebook()
        pass


    def run_jupyter_notebooks(self,project_nr,notebook_names):
        '''runs a jupyter notebook'''
        notebook_path = f'code/project{project_nr}/src/'

        for notebook_name in notebook_names:
            self.run_jupyter_notebook.run_notebook(f'{notebook_path}{notebook_name}')

    def convert_notebooks_to_pdf(self,project_nr,notebook_names):
        '''converts a jupyter notebook to pdf'''
        notebook_path = f'code/project{project_nr}/src/'

        for notebook_name in notebook_names:
            self.run_jupyter_notebook.convert_notebook_to_pdf(f'{notebook_path}{notebook_name}')

    def export_code_to_latex(self, project_nr):
        export_code_to_latex('main.tex', project_nr)

    def compile_latex_report(self,project_nr):
        '''compiles latex code to pdf'''
        compile_latex =Compile_latex(project_nr ,'main.tex')

    ##############################################################
    ############example code to illustrate python-latex  image sync #########
    ###############runs arbitrary genetic algorithm, can be deleted ###########
    ##############################################################
    def count(self,bits):
        count = 0
        for bit in bits:
            if bit:
                count = count + 1
        return count
```

```
57
58      def gen_bit_sequence(self):
59          bits = []
60          for _ in range(string_length):
61              bits.append(True if random.randint(0, 1) == 1 else False)
62          return bits
63
64      def mutate_bit_sequence(self,sequence):
65          retval = []
66          for bit in sequence :
67              do_mutation = random.random() <= mutation_chance
68              if(do_mutation):
69                  retval.append(not bit)
70              else:
71                  retval.append(bit)
72          return retval
73
74      #execute a run a
75      def do_run_a(self):
76
77          seq = self.gen_bit_sequence()
78          fitness = self.count(seq)
79          results = [fitness]
80          for run in range(max_iterations-1):
81              new_seq = self.mutate_bit_sequence(seq)
82              new_fitness = self.count(new_seq)
83              if new_fitness > fitness:
84                  seq = new_seq
85                  fitness = new_fitness
86              results.append(max(results[-1],fitness))
87          return results
88
89
90      #execute a run c
91      def do_run_c(self):
92          seq = self.gen_bit_sequence()
93          fitness = self.count(seq)
94          results = [fitness]
95          for run in range(max_iterations):
96              new_seq = self.mutate_bit_sequence(seq)
97              new_fitness = self.count(new_seq)
98              seq = new_seq
99              fitness = new_fitness
100             results.append(max(results[-1], fitness))
101         return results
102
103     def do4b(self,project_nr):
104         optimum_found = 0
105
106         # generate plot data
107         plotResult = np.zeros((10,max_iterations), dtype=int);
108         lineLabels = []
109
110         # perform computation
111         for run in range(10):
112             res = self.do_run_a()
113             if res[-1] == string_length:
114                 optimum_found +=1
115
116             # store computation data for plotting
117             lineLabels.append(f'Run {run}')
118             plotResult[run,:]=res;
```

```
119
120         # plot multiple lines into report (res is an array of
                ↪ dataseries (representing the lines))
121         # plt_tex.plotMultipleLines(plt_tex,x,y,"x-axis label","y-
                ↪ axis label",lineLabels,"filename",legend_position,
                ↪ project_nr)
122         plt_tex.plotMultipleLines(plt_tex,range(0, len(res)),
                ↪ plotResult,"[runs]]","fitness [%]",lineLabels,"4b",4,
                ↪ project_nr)
123         print("total optimum found: {} out of {} runs".format(
                ↪ optimum_found,10))
124
125     def do4c(self,project_nr):
126         optimum_found = 0
127
128         # generate plot data
129         plotResult = np.zeros((10,max_iterations+1), dtype=int);
130         lineLabels = []
131
132         # perform computation
133         for run in range(10):
134             res = self.do_run_c()
135             if res[-1] == string_length:
136                 optimum_found +=1
137
138             # Store computation results for plot
139             lineLabels.append(f'Run {run}')
140             plotResult[run,:]=res;
141
142         # plot multiple lines into report (res is an array of
                ↪ dataseries (representing the lines))
143         # plt_tex.plotMultipleLines(plt_tex,x,y,"x-axis label","y-
                ↪ axis label",lineLabels,"filename",legend_position,
                ↪ project_nr)
144         plt_tex.plotMultipleLines(plt_tex,range(0, len(res)),
                ↪ plotResult,"[runs]]","fitness [%]",lineLabels,"4c",4,
                ↪ project_nr)
145
146         print("total optimum found: {} out of {} runs".format(
                ↪ optimum_found, 10))
147
148     def addTwo(self,x):
149         ''' adds two to the incoming integer and returns the result
                ↪ of the computation.'''
150         return x+2
151
152 if __name__ == '__main__':
153     # initialize main class
154     main = Main()
```

C Appendix Compile_latex.py

```
# runs a jupyter notebook and converts it to pdf

import os
import shutil
import nbformat
from nbconvert.preprocessors import ExecutePreprocessor

class Compile_latex:

    def __init__(self,project_nr,latex_filename):
        self.script_dir = self.get_script_dir()
        relative_dir = f'latex/project{project_nr}/'
        self.compile_latex(relative_dir,latex_filename)
        self.clean_up_after_compilation(latex_filename)
        self.move_pdf_into_latex_dir(relative_dir,latex_filename)

    # runs jupyter notebook
    def compile_latex(self,relative_dir,latex_filename):
        os.system(f'pdflatex {relative_dir}{latex_filename}')

    def clean_up_after_compilation(self,latex_filename):
        latex_filename_without_extention = latex_filename[:-4]
        print(f'latex_filename_without_extention={
            ↪ latex_filename_without_extention}')
        self.delete_file_if_exists(f'{
            ↪ latex_filename_without_extention}.aux')
        self.delete_file_if_exists(f'{
            ↪ latex_filename_without_extention}.log')
        self.delete_file_if_exists(f'texput.log')

    def move_pdf_into_latex_dir(self,relative_dir,latex_filename):
        pdf_filename = f'{latex_filename[:-4]}.pdf'
        destination= f'{self.get_script_dir()}/../../../{relative_dir
            ↪ }{pdf_filename}'

        try:
            shutil.move(pdf_filename, destination)
        except:
            print("Error while moving file ", pdf_filename)

    def delete_file_if_exists(self,filename):
        try:
            os.remove(filename)
        except:
            print(f'Error while deleting file: {filename} but that is
                ↪  not too bad because the intention is for it to not
                ↪  be there.')

    def get_script_dir(self):
        ''' returns the directory of this script regardles of from
            ↪ which level the code is executed '''
        return os.path.dirname(__file__)

if __name__ == '__main__':
    main = Compile_latex()
```

D Appendix Export_code_to_latex.py

```
# runs a jupyter notebook and converts it to pdf
import os
import shutil
import nbformat
from nbconvert.preprocessors import ExecutePreprocessor

def export_code_to_latex(main_latex_filename, project_nr):
    """

    :param main_latex_filename:
    :param project_nr:

    """
    script_dir = get_script_dir()
    relative_dir = f'latex/project{project_nr}/'
    appendix_dir = script_dir+'/../../../'+relative_dir+'Appendices/'
    path_to_main_latex_file = f'{script_dir}/../../../{relative_dir}/{main_latex_filename}'
    root_dir = script_dir[0:script_dir.rfind(f'code/project{project_nr}')]

    python_filepaths = get_filenames_in_dir('py',script_dir, ['__init__.py'])
    compiled_notebook_pdf_filepaths = get_compiled_notebook_paths(script_dir)

    python_files_already_included_in_appendices = get_code_files_already_included_in_appendices(python_filepaths, appendix_dir, '.py', project_nr, root_dir)
    notebook_pdf_files_already_included_in_appendices = get_code_files_already_included_in_appendices(compiled_notebook_pdf_filepaths, appendix_dir, '.ipynb', project_nr, root_dir)

    missing_python_files_in_appendices = get_code_files_not_yet_included_in_appendices(python_filepaths, python_files_already_included_in_appendices, '.py')
    missing_notebook_files_in_appendices = get_code_files_not_yet_included_in_appendices(compiled_notebook_pdf_filepaths, notebook_pdf_files_already_included_in_appendices, '.pdf')

    created_python_appendix_filenames = create_appendices_with_code(appendix_dir, missing_python_files_in_appendices, '.py', project_nr, root_dir)
    created_notebook_appendix_filenames = create_appendices_with_code(appendix_dir, missing_notebook_files_in_appendices, '.ipynb', project_nr, root_dir)

    appendices = get_list_of_appendix_files(appendix_dir, compiled_notebook_pdf_filepaths, python_filepaths)

    main_tex_code, start_index, end_index, appendix_tex_code = get_appendix_tex_code(path_to_main_latex_file)
    # assumes non-included non-code appendices should not be included :
    non_code_appendices, main_non_code_appendix_inclusion_lines = get_order_of_non_code_appendices_in_main(appendices,
```

```
        ↪ appendix_tex_code)

    python_appendix_filenames = list(map(lambda x: x.
        ↪ appendix_filename, filter_appendices_by_type(appendices, '
        ↪ python')))
    sorted_created_python_appendices = sort_python_appendices(
        ↪ filter_appendices_by_type(appendices, 'python'))
    sorted_python_appendix_filenames = list(map(lambda x: x.
        ↪ appendix_filename, sorted_created_python_appendices))

    notebook_appendix_filenames = list(map(lambda x: x.
        ↪ appendix_filename, filter_appendices_by_type(appendices, '
        ↪ notebook')))
    sorted_created_notebook_appendices = sort_notebook_appendices(
        ↪ filter_appendices_by_type(appendices, 'notebook'))
    sorted_notebook_appendix_filenames = list(map(lambda x: x.
        ↪ appendix_filename, sorted_created_notebook_appendices))

    appendix_latex_code = create_appendices_latex_code(
        ↪ main_non_code_appendix_inclusion_lines,
        ↪ sorted_created_notebook_appendices, project_nr,
        ↪ sorted_created_python_appendices)

    updated_main_tex_code = substitute_appendix_code(end_index,
        ↪ main_tex_code, start_index, appendix_latex_code)

    overwrite_content_to_file(updated_main_tex_code,
        ↪ path_to_main_latex_file)


def create_appendices_latex_code(
    ↪ main_non_code_appendix_inclusion_lines, notebook_appendices,
    ↪ project_nr, python_appendices):
    """creates the appendix text for main.

    :param main_non_code_appendix_inclusion_lines:
    :param notebook_appendices:
    :param project_nr:
    :param python_appendices:

    """
    main_appendix_inclusion_lines =
        ↪ main_non_code_appendix_inclusion_lines
    for appendix in python_appendices:
        line = update_appendix_tex_code(appendix.appendix_filename,
            ↪ project_nr)
        main_appendix_inclusion_lines.append(line)

    for appendix in notebook_appendices:
        line = update_appendix_tex_code(appendix.appendix_filename,
            ↪ project_nr)
        main_appendix_inclusion_lines.append(line)
    return main_appendix_inclusion_lines


def filter_appendices_by_type(appendices, appendix_type):
    """Returns the list of appendices of certain type from a list of
        ↪ appendix objects.

    :param appendices:
    :param appendix_type:

```

```
    """
    return_appendices = []
    for appendix in appendices:
        if appendix.appendix_type == appendix_type:
            return_appendices.append(appendix)
    return return_appendices


def sort_python_appendices(appendices):
    """First puts __main__.py, followed by main.py followed by a-z
       ↪ code files.

    :param appendices:

    """
    return_appendices = []
    for appendix in appendices: # first get appendix containing
       ↪ __main__.py
        if (appendix.code_filename=="__main__.py") or (appendix.
           ↪ code_filename=="__Main__.py"):
            return_appendices.append(appendix)
            appendices.remove(appendix)
    for appendix in appendices: # second get appendix containing main
       ↪ .py
        if (appendix.code_filename=="main.py") or (appendix.
           ↪ code_filename=="Main.py"):
            return_appendices.append(appendix)
            appendices.remove(appendix)
    return_appendices

    # Filter remaining appendices in order of a-z
    filtered_remaining_appendices = [i for i in appendices if i.
       ↪ code_filename is not None]
    appendices_sorted_a_z = filter_list_on_property(
       ↪ filtered_remaining_appendices)
    return return_appendices+appendices_sorted_a_z


def sort_notebook_appendices(appendices):
    """Sorts notebooks on a-z pdf filenames.

    :param appendices:

    """
    return_appendices = []
    filtered_remaining_appendices = [i for i in appendices if i.
       ↪ code_filename is not None]
    appendices_sorted_a_z = filter_list_on_property(
       ↪ filtered_remaining_appendices)
    return return_appendices+appendices_sorted_a_z


def filter_list_on_property(appendices):
    """Returns a list based on the property: code_filename

    :param appendices:

    """
    attributes = list(map(lambda x: x.code_filename, appendices))
    sorted_indices = sorted(range(len(attributes)), key=lambda k:
       ↪ attributes[k])
    sorted_list = []
```

```
131     for i in sorted_indices:
132         sorted_list.append(appendices[i])
133     return sorted_list
134 
135 
136 def get_order_of_non_code_appendices_in_main(appendices,
    ↪ appendix_tex_code):
137     """Scans the lines of appendices in the main code, and returns
        ↪ the lines that
138     of appendices that do not contain code, in specified order.
139 
140     :param appendices:
141     :param appendix_tex_code:
142 
143     """
144     non_code_appendices = []
145     non_code_appendix_lines = []
146     appendix_tex_code = list(dict.fromkeys(appendix_tex_code))
147     for line in appendix_tex_code:
148         appendix_filename = get_filename_from_latex_appendix_line(
            ↪ appendices, line)
149 
150         # Check if line is not commented
151         if not appendix_filename is None:
152             if not line_is_commented(line,appendix_filename):
153                 appendix = get_appendix_from_filename(appendices,
                    ↪ appendix_filename)
154                 if appendix.appendix_type == "no_code":
155                     non_code_appendices.append(appendix)
156                     non_code_appendix_lines.append(line)
157     return non_code_appendices, non_code_appendix_lines
158 
159 
160 def get_filename_from_latex_appendix_line(appendices, appendix_line):
161     """
162 
163     :param appendices:
164     :param appendix_line:
165 
166     """
167     for filename in list(map(lambda appendix: appendix.
        ↪ appendix_filename, appendices)):
168         if filename in appendix_line:
169             return filename
170 
171 
172 def get_appendix_from_filename(appendices, appendix_filename):
173     """
174 
175     :param appendices:
176     :param appendix_filename:
177 
178     """
179     for appendix in appendices:
180         if appendix_filename == appendix.appendix_filename:
181             return appendix
182 
183 
184 def get_compiled_notebook_paths(script_dir):
185     """Returns the list of jupiter notebook filepaths that were
        ↪ compiled successfully
186 
```

```
187     :param script_dir:
188
189     """
190     notebook_filepaths= get_filenames_in_dir('.ipynb', script_dir)
191     compiled_notebook_filepaths = []
192
193     # check if the jupyter notebooks were compiled
194     for notebook_filepath in notebook_filepaths:
195
196         # swap file extension
197         notebook_filepath = notebook_filepath.replace('.ipynb','.pdf'
                ↪ )
198
199         # check if file exists
200         if os.path.isfile(notebook_filepath):
201             compiled_notebook_filepaths.append(notebook_filepath)
202     return compiled_notebook_filepaths
203
204
205 def get_list_of_appendix_files(appendix_dir,
        ↪ absolute_notebook_filepaths, absolute_python_filepaths):
206     """Returns a list with all the appendix files with .tex extension
            ↪ .
207
208     :param appendix_dir:
209     :param absolute_notebook_filepaths:
210     :param absolute_python_filepaths:
211
212     """
213     appendices = []
214     appendices_paths = get_filenames_in_dir('.tex', appendix_dir)
215
216     for appendix_filepath in appendices_paths:
217         appendix_type = "no_code"
218         appendix_filecontent = read_file(appendix_filepath)
219         line_nr_python_file_inclusion = get_line_of_latex_command(
                ↪ appendix_filecontent, "\pythonexternal{")
220         line_nr_notebook_file_inclusion = get_line_of_latex_command(
                ↪ appendix_filecontent, "\includepdf[pages=")
221         if  line_nr_python_file_inclusion > -1:
222             appendix_type = "python"
223             # get python filename
224             line = appendix_filecontent[line_nr_python_file_inclusion
                    ↪ ]
225             filename = get_filename_from_latex_inclusion_command(line
                    ↪ , '.py', "\pythonexternal{")
226             appendices.append(Appendix(appendix_filepath,
                    ↪ appendix_filecontent, appendix_type, filename, line
                    ↪ ))
227         if line_nr_notebook_file_inclusion > -1:
228             appendix_type = "notebook"
229             line = appendix_filecontent[
                    ↪ line_nr_notebook_file_inclusion]
230             filename = get_filename_from_latex_inclusion_command(
                    ↪ line, '.pdf', "\includepdf[pages=")
231             appendices.append(Appendix(appendix_filepath,
                    ↪ appendix_filecontent, appendix_type, filename, line
                    ↪ ))
232         else:
233             appendices.append(Appendix(appendix_filepath,
                    ↪ appendix_filecontent, appendix_type))
234     return appendices
```

```
235
236
237 def get_filename_from_latex_inclusion_command(appendix_line,
    ↪ extension, start_substring):
238     """returns the filename in a latex inclusion command that is
        ↪ located in an appendix.
239     The inclusion command includes a python code or jupiter notebook
        ↪ pdf.
240
241     :param appendix_line:
242     :param extension:
243     :param start_substring:
244
245     """
246     start_index = appendix_line.index(start_substring)
247     end_index = appendix_line.index(extension)
248     return get_filename_from_dir(appendix_line[start_index:end_index+
        ↪ len(extension)])
249
250
251 def get_filenames_in_dir(extension, path, excluded_files=None):
252     """Returns a list of the relative paths to all files within the
        ↪ code/projectX/src/ folder that match
253     the given file extension.
254
255     :param extension:
256     :param path:
257     :param excluded_files:  (Default value = None)
258
259     """
260     filepaths=[]
261     for r, d, f in os.walk(path):
262         for file in f:
263             if file.endswith(extension):
264                 if (excluded_files is None) or ((not excluded_files
                    ↪ is None) and (not file in excluded_files)):
265                     filepaths.append(r+'/'+file)
266     return filepaths
267
268
269 def get_code_files_already_included_in_appendices(absolute_filepaths,
    ↪  appendix_dir, extension, project_nr, root_dir):
270     """Returns a list of filepaths that are already properly included
        ↪  in some appendix of this projectX,
271
272     :param absolute_filepaths:
273     :param appendix_dir:
274     :param extension:
275     :param project_nr:
276     :param root_dir:
277
278     """
279     appendix_files = get_filenames_in_dir('.tex', appendix_dir)
280     contained_codes = []
281     for code_filepath in absolute_filepaths:
282         for appendix_filepath in appendix_files:
283             appendix_filecontent = read_file(appendix_filepath)
284             line_nr = check_if_appendix_contains_file(
                ↪ appendix_filecontent, code_filepath, extension,
                ↪ project_nr, root_dir)
285             if line_nr>-1:
```

```
286                 # add filepath to list of files that are already in
                        ↪ the appendices
287                 contained_codes.append(Appendix_with_code(
                        ↪ code_filepath,
288                 appendix_filepath,
289                 appendix_filecontent,
290                 line_nr,
291                 '.py'))
292     return contained_codes
293 
294 
295 def check_if_appendix_contains_file(appendix_content, code_filepath,
        ↪ extension, project_nr, root_dir):
296     """scans an appendix content to determine whether it contains a
            ↪ substring that
297     includes the python code file.
298 
299     :param appendix_content:
300     :param code_filepath:
301     :param extension:
302     :param project_nr:
303     :param root_dir:
304 
305     """
306     # convert code_filepath to the inclusion format in latex format
307     latex_relative_filepath = f'latex/project{project_nr}/../../{
            ↪ code_filepath[len(root_dir):]}'
308     latex_command = get_latex_inclusion_command(extension,
            ↪ latex_relative_filepath)
309     return get_line_of_latex_command(appendix_content, latex_command)
310 
311 
312 def get_line_of_latex_command(appendix_content, latex_command):
313     """Returns the line number of a latex command if it is found.
            ↪ Returns -1 otherwise.
314 
315     :param appendix_content:
316     :param latex_command:
317 
318     """
319     # check if the file is in the latex code
320     line_nr = 0
321     for line in appendix_content:
322         if latex_command in line:
323             if line_is_commented(line,latex_command):
324                 commented=True
325             else:
326                 return line_nr
327         line_nr=line_nr+1
328     return -1
329 
330 
331 def line_is_commented(line, target_substring):
332     """Returns true if a line is commented, returns false otherwise
333 
334     :param line:
335     :param target_substring:
336 
337     """
338     left_of_command = line[:line.rfind(target_substring)]
339     if '%' in left_of_command:
340         return True
```

```
341     return False
342 
343 
344 def get_latex_inclusion_command(extension,
    ↪ latex_relative_filepath_to_codefile):
345     """
346 
347     :param extension:
348     :param latex_relative_filepath_to_codefile:
349 
350     """
351     if extension==".py":
352         left = "\pythonexternal{"
353         right = "}"
354         latex_command = f'{left}{latex_relative_filepath_to_codefile
            ↪ }{right}'
355     elif extension==".ipynb":
356 
357         left = "\includepdf[pages=-]{"
358         right = "}"
359         latex_command = f'{left}{latex_relative_filepath_to_codefile
            ↪ }{right}'
360     return latex_command
361 
362 
363 def read_file(filepath):
364     """Reads content of a file and returns it as a list of strings
365 
366     :param filepath:
367 
368     """
369     with open(filepath) as f:
370         content = f.readlines()
371     return content
372 
373 
374 def get_code_files_not_yet_included_in_appendices(code_filepaths,
    ↪ contained_codes, extension):
375     """Returns a list of filepaths that are not yet properly included
        ↪  in some appendix of this projectX,
376 
377     :param code_filepaths:
378     :param contained_codes:
379     :param extension:
380 
381     """
382     contained_filepaths = list(map(lambda contained_file:
        ↪ contained_file.code_filepath, contained_codes))
383     not_contained = []
384     for filepath in code_filepaths:
385         if not filepath in contained_filepaths:
386             not_contained.append(filepath)
387     return not_contained
388 
389 
390 def create_appendices_with_code(appendix_dir, code_filepaths,
    ↪ extension, project_nr, root_dir):
391     """Creates the latex appendix files in with relevant codes
        ↪ included.
392 
393     :param appendix_dir:
394     :param code_filepaths:
```

```
395     :param extension:
396     :param project_nr:
397     :param root_dir:
398 
399     """
400     appendix_filenames = []
401     appendix_reference_index = 0
402 
403     for code_filepath in code_filepaths:
404         latex_relative_filepath = f'latex/project{project_nr}/../../{
            ↪ code_filepath[len(root_dir):]}'
405         content = []
406         filename = get_filename_from_dir(code_filepath)
407         content = create_section(appendix_reference_index, filename,
            ↪ content)
408         inclusion_command = get_latex_inclusion_command(extension,
            ↪ latex_relative_filepath)
409         content.append(inclusion_command)
410         overwrite_content_to_file(content, f'{appendix_dir}
            ↪ Auto_generated_{extension[1:]}_App{
            ↪ appendix_reference_index}.tex', False)
411         appendix_filenames.append(f'Auto_generated_{extension[1:]}
            ↪ _App{appendix_reference_index}.tex')
412         appendix_reference_index = appendix_reference_index+1
413     return appendix_filenames
414 
415 
416 def create_section(appendix_reference_index, code_filename, content):
417     """
418 
419     :param appendix_reference_index:
420     :param code_filename:
421     :param content:
422 
423     """
424     # write section
425     left ="\section{Appendix "
426     middle = code_filename.replace("_","\_")
427     right = "}\label{app:"
428     end = "}" # TODO: update appendix reference index
429     content.append(f'{left}{middle}{right}{appendix_reference_index}{
        ↪ end}')
430     return content
431 
432 
433 def overwrite_content_to_file(content, filepath, content_has_newlines
    ↪ =True):
434     """Writes the content of an appendix to a new appendix
435 
436     :param content:
437     :param filepath:
438     :param content_has_newlines:  (Default value = True)
439 
440     """
441     with open(filepath,'w') as f:
442         for line in content:
443             if content_has_newlines:
444                 f.write(line)
445             else:
446                 f.write(line+'\n')
447 
448 
```

```
449 def get_appendix_tex_code(main_latex_filename):
450     """gets the latex appendix code from the main tex file.
451 
452     :param main_latex_filename:
453 
454     """
455     main_tex_code = read_file(main_latex_filename)
456     start =  "\\begin{appendices}"
457     end = "\end{appendices}"
458     start_index = get_index_of_substring_in_list(main_tex_code, start
        ↪ )+1
459     end_index = get_index_of_substring_in_list(main_tex_code, end)
460     return main_tex_code, start_index, end_index, main_tex_code[
        ↪ start_index:end_index]
461 
462 
463 def get_index_of_substring_in_list(lines, target_substring):
464     """
465 
466     :param lines:
467     :param target_substring:
468 
469     """
470     for i in range(0, len(lines)):
471         if target_substring in lines[i]:
472             if not line_is_commented(lines[i], target_substring):
473                 return i
474 
475 
476 def update_appendix_tex_code(appendix_filename, project_nr):
477     """Includes the appendices as latex commands in the tex code
        ↪ string
478 
479     :param appendix_filename:
480     :param project_nr:
481 
482     """
483     left = "\input{latex/project"
484     middle = "/Appendices/"
485     right = "} \\newpage\n"
486     return f'{left}{project_nr}{middle}{appendix_filename}{right}'
487 
488 
489 def substitute_appendix_code(end_index, main_tex_code, start_index,
    ↪ updated_appendices_tex_code):
490     """Replaces the old latex code that include the appendices with
        ↪ the new latex
491     commands that include the appendices in the latex report.
492 
493     :param end_index:
494     :param main_tex_code:
495     :param start_index:
496     :param updated_appendices_tex_code:
497 
498     """
499     updated_main_tex_code = main_tex_code[0:start_index]+
        ↪ updated_appendices_tex_code+main_tex_code[end_index:]
500     return updated_main_tex_code
501 
502 
503 def get_filename_from_dir(path):
504     """
```

```
505
506         :param path:
507
508         """
509         return path[path.rfind("/")+1:]
510
511
512 def get_script_dir():
513         """returns the directory of this script regardles of from which
                ↪ level the code is executed"""
514         return os.path.dirname(__file__)
515
516
517 class Appendix_with_code:
518         """stores in which appendix file and accompanying line number in
                ↪ the appendix in which a code file is
519         already included. Does not take into account whether this
                ↪ appendix is in the main tex file or not
520
521
522         """
523         def __init__(self, code_filepath, appendix_filepath,
                ↪ appendix_content, file_line_nr, extension):
524             self.code_filepath = code_filepath
525             self.appendix_filepath = appendix_filepath
526             self.appendix_content = appendix_content
527             self.file_line_nr = file_line_nr
528             self.extension = extension
529
530
531 class Appendix:
532         """stores in appendix files and type of appendix."""
533         def __init__(self, appendix_filepath, appendix_content,
                ↪ appendix_type, code_filename=None, appendix_inclusion_line=
                ↪ None):
534             self.appendix_filepath = appendix_filepath
535             self.appendix_filename = get_filename_from_dir(self.
                    ↪ appendix_filepath)
536             self.appendix_content = appendix_content
537             self.appendix_type = appendix_type # TODO: perform validation
                    ↪  of input values
538             self.code_filename = code_filename
539             self.appendix_inclusion_line = appendix_inclusion_line
```

E Appendix Plot_to_tex.py

```
### Call this from another file, for project 11, question 3b:
### from Plot_to_tex import Plot_to_tex as plt_tex
### multiple_y_series = np.zeros((nrOfDataSeries,nrOfDataPoints), dtype=int); # actually fill with data
### lineLabels = [] # add a label for each dataseries
### plt_tex.plotMultipleLines(plt_tex,single_x_series, multiple_y_series,"x-axis label [units]","y-axis label [units]",lineLabels,"3b",4,11)
### 4b=filename
### 4 = position of legend, e.g. top right.
###
### For a single line, use:
### plt_tex.plotSingleLine(plt_tex,range(0, len(dataseries)), dataseries,"x-axis label [units]","y-axis label [units]", lineLabel,"3b",4,11)

### You can also plot a table directly into latex, see example_create_a_table(..)
###
### Then put it in latex with for example:
###\begin{table}[H]
###     \centering
###     \caption{Results some computation.}\label{tab:some_computation}
###     \begin{tabular}{|c|c|} % remember to update this to show all columns of table
###         \hline
###         \input{latex/project3/tables/q2.txt}
###     \end{tabular}
###\end{table}
import random
from matplotlib import lines
import matplotlib.pyplot as plt
import numpy as np
import os
class Plot_to_tex:

    def __init__(self):
        self.script_dir = self.get_script_dir()
        print("Created main")

    # plot graph (legendPosition = integer 1 to 4)
    def plotSingleLine(self,x_path,y_series,x_axis_label,y_axis_label ,label,filename,legendPosition,project_nr):
        fig=plt.figure();
        ax=fig.add_subplot(111);
        ax.plot(x_path,y_series,c='b',ls='-',label=label,fillstyle='none');
        plt.legend(loc=legendPosition);
        plt.xlabel(x_axis_label);
        plt.ylabel(y_axis_label);
        plt.savefig(os.path.dirname(__file__)+'/../../../latex/project'+str(project_nr)+'/Images/'+filename+'.png');
#         plt.show();

    # plot graphs
    def plotMultipleLines(self,x,y_series,x_label,y_label,label, filename,legendPosition,project_nr):
        fig=plt.figure();
        ax=fig.add_subplot(111);
```

```
49
50          # generate colours
51          cmap = self.get_cmap(len(y_series[:,0]))
52
53          # generate line types
54          lineTypes = self.generateLineTypes(y_series)
55
56          for i in range(0,len(y_series)):
57              # overwrite linetypes to single type
58              lineTypes[i] = "-"
59              ax.plot(x,y_series[i,:],ls=lineTypes[i],label=label[i],
                    ↪ fillstyle='none',c=cmap(i)); # color
60
61          # configure plot layout
62          plt.legend(loc=legendPosition);
63          plt.xlabel(x_label);
64          plt.ylabel(y_label);
65          plt.savefig(os.path.dirname(__file__)+'/../../../latex/
                ↪ project'+str(project_nr)+'/Images/'+filename+'.png');
66
67          print(f'plotted lines')
68
69      # Generate random line colours
70      # Source: https://stackoverflow.com/questions/14720331/how-to-
            ↪ generate-random-colors-in-matplotlib
71      def get_cmap(n, name='hsv'):
72          '''Returns a function that maps each index in 0, 1, ..., n-1
                ↪ to a distinct
73          RGB color; the keyword argument name must be a standard mpl
                ↪ colormap name.'''
74          return plt.cm.get_cmap(name, n)
75
76      def generateLineTypes(y_series):
77          # generate varying linetypes
78          typeOfLines = list(lines.lineStyles.keys())
79
80          while(len(y_series)>len(typeOfLines)):
81              typeOfLines.append("-.");
82
83          # remove void lines
84          for i in range(0, len(y_series)):
85              if (typeOfLines[i]=='None'):
86                  typeOfLines[i]='-'
87              if (typeOfLines[i]==''):
88                  typeOfLines[i]=':'
89              if (typeOfLines[i]==' '):
90                  typeOfLines[i]='--'
91          return typeOfLines
92
93      # Create a table with: table_matrix = np.zeros((4,4),dtype=object
            ↪ ) and pass it to this object
94      def put_table_in_tex(self, table_matrix,filename,project_nr):
95          cols = np.shape(table_matrix)[1]
96          format = "%s"
97          for col in range(1,cols):
98              format = format+" & %s"
99          format = format+""
100         plt.savetxt(os.path.dirname(__file__)+"/../../../latex/
                ↪ project"+str(project_nr)+"/tables/"+filename+".txt",
                ↪ table_matrix, delimiter=' & ', fmt=format, newline='
                ↪ \\\\ \hline \n')
101
```

```
102     # replace this with your own table creation and then pass it to
          ↪ put_table_in_tex(..)
103     def example_create_a_table(self):
104         project_nr = "1"
105         table_name = "example_table_name"
106         rows = 2;
107         columns = 4;
108         table_matrix = np.zeros((rows,columns),dtype=object)
109         table_matrix[:,:]="" # replace the standard zeros with emtpy
              ↪ cell
110         print(table_matrix)
111         for column in range(0,columns):
112             for row in range(0,rows):
113                 table_matrix[row,column]=row+column
114         table_matrix[1,0]="example"
115         table_matrix[0,1]="grid sizes"
116 
117         self.put_table_in_tex(table_matrix,table_name,project_nr)
118 
119 
120     def get_script_dir(self):
121         ''' returns the directory of this script regardles of from
              ↪ which level the code is executed '''
122         return os.path.dirname(__file__)
123 
124 if __name__ == '__main__':
125     main = Plot_to_tex()
126     main.example_create_a_table()
```

F Appendix Run_jupyter_notebooks.py

```
# runs a jupyter notebook and converts it to pdf

import os
import nbformat
from nbconvert.preprocessors import ExecutePreprocessor

class Run_jupyter_notebook:

    def __init__(self):
        self.script_dir = self.get_script_dir()
        print("Created main")

    # runs jupyter notebook
    def run_notebook(self,notebook_filename):


        # Load your notebook
        with open(notebook_filename) as f:
            nb = nbformat.read(f, as_version=4)

        # Configure
        ep = ExecutePreprocessor(timeout=600, kernel_name='python3')

        # Execute
        ep.preprocess(nb, {'metadata': {'path': f'{self.
           ↪ get_script_dir()}/../../../'}})

        # Save output notebook
        with open(notebook_filename, 'w', encoding='utf-8') as f:
            nbformat.write(nb, f)

    # converts jupyter notebook to pdf
    def convert_notebook_to_pdf(self,notebook_filename):
        os.system(f'jupyter nbconvert --to pdf {notebook_filename}')

    def get_script_dir(self):
        ''' returns the directory of this script regardles of from
           ↪ which level the code is executed '''
        return os.path.dirname(__file__)

if __name__ == '__main__':
    main = Run_jupyter_notebook()
```

Appendix Example Jupyter Notebook

AE4868_example_notebook_update20201025

December 26, 2020

[1]:
```
def addThree(input_nr):
    '''returns the input integer plus 3, used to verify unit test'''
    return input_nr + 3
```

[2]:
```
##############################################################################
# IMPORT STATEMENTS ##########################################################
##############################################################################
import os
import numpy as np
from tudatpy.kernel import constants
from tudatpy.kernel.interface import spice_interface
from tudatpy.kernel.simulation import environment_setup
from tudatpy.kernel.simulation import propagation_setup
from tudatpy.kernel.astro import conversion

# Set path to latex image folders for project 1
latex_image_path = 'latex/project1/Images/'

# Load spice kernels.
spice_interface.load_standard_kernels()

# Set simulation start and end epochs.
simulation_start_epoch = 0.0
simulation_end_epoch = constants.JULIAN_DAY

##############################################################################
# CREATE ENVIRONMENT #########################################################
##############################################################################

# Create default body settings for selected celestial bodies
bodies_to_create = ["Sun", "Earth", "Moon", "Mars", "Venus"]

# Create default body settings for bodies_to_create, with "Earth"/"J2000" as
# global frame origin and orientation. This environment will only be valid
# in the indicated time range
# [simulation_start_epoch --- simulation_end_epoch]
body_settings = environment_setup.get_default_body_settings(
```

```
    bodies_to_create,
    simulation_start_epoch,
    simulation_end_epoch,
    "Earth","J2000")

# Create system of selected celestial bodies
bodies = environment_setup.create_system_of_bodies(body_settings)

################################################################################
# CREATE VEHICLE ###############################################################
################################################################################

# Create vehicle objects.
bodies.create_empty_body( "Delfi-C3" )
bodies.get_body( "Delfi-C3").set_constant_mass(400.0)

# Create aerodynamic coefficient interface settings, and add to vehicle
reference_area = 4.0
drag_coefficient = 1.2
aero_coefficient_settings = environment_setup.aerodynamic_coefficients.constant(
    reference_area,[drag_coefficient,0,0]
)
environment_setup.add_aerodynamic_coefficient_interface(
            bodies, "Delfi-C3", aero_coefficient_settings )

# Create radiation pressure settings, and add to vehicle
reference_area_radiation = 4.0
radiation_pressure_coefficient = 1.2
occulting_bodies = ["Earth"]
radiation_pressure_settings = environment_setup.radiation_pressure.cannonball(
    "Sun", reference_area_radiation, radiation_pressure_coefficient,␣
 ↪occulting_bodies
)
environment_setup.add_radiation_pressure_interface(
            bodies, "Delfi-C3", radiation_pressure_settings )

################################################################################
# CREATE ACCELERATIONS #########################################################
################################################################################

# Define bodies that are propagated.
bodies_to_propagate = ["Delfi-C3"]

# Define central bodies.
central_bodies = ["Earth"]

# Define accelerations acting on Delfi-C3 by Sun and Earth.
```

```
accelerations_settings_delfi_c3 = dict(
    Sun=
    [
        propagation_setup.acceleration.cannonball_radiation_pressure(),
        propagation_setup.acceleration.point_mass_gravity()
    ],
    Earth=
    [
        propagation_setup.acceleration.spherical_harmonic_gravity(5, 5),
        propagation_setup.acceleration.aerodynamic()
    ])

# Define point mass accelerations acting on Delfi-C3 by all other bodies.
for other in set(bodies_to_create).difference({"Sun", "Earth"}):
    accelerations_settings_delfi_c3[other] = [
        propagation_setup.acceleration.point_mass_gravity()]

# Create global accelerations settings dictionary.
acceleration_settings = {"Delfi-C3": accelerations_settings_delfi_c3}

# Create acceleration models.
acceleration_models = propagation_setup.create_acceleration_models(
    bodies,
    acceleration_settings,
    bodies_to_propagate,
    central_bodies)

###########################################################################
# CREATE PROPAGATION SETTINGS #############################################
###########################################################################

# Set initial conditions for the Asterix satellite that will be
# propagated in this simulation. The initial conditions are given in
# Keplerian elements and later on converted to Cartesian elements.
earth_gravitational_parameter = bodies.get_body( "Earth" ).
 ↪gravitational_parameter
initial_state = conversion.keplerian_to_cartesian(
    gravitational_parameter=earth_gravitational_parameter,
    semi_major_axis=7500.0E3,
    eccentricity=0.1,
    inclination=np.deg2rad(85.3),
    argument_of_periapsis=np.deg2rad(235.7),
    longitude_of_ascending_node=np.deg2rad(23.4),
    true_anomaly=np.deg2rad(139.87)
)

# Define list of dependent variables to save.
```

```
dependent_variables_to_save = [
    propagation_setup.dependent_variable.total_acceleration( "Delfi-C3" ),
    propagation_setup.dependent_variable.keplerian_state( "Delfi-C3", "Earth" ),
    propagation_setup.dependent_variable.latitude( "Delfi-C3", "Earth" ),
    propagation_setup.dependent_variable.longitude( "Delfi-C3", "Earth"),
    propagation_setup.dependent_variable.single_acceleration_norm(
        propagation_setup.acceleration.point_mass_gravity_type, "Delfi-C3",␣
 ↪"Sun"
    ),
    propagation_setup.dependent_variable.single_acceleration_norm(
        propagation_setup.acceleration.point_mass_gravity_type, "Delfi-C3",␣
 ↪"Moon"
    ),
    propagation_setup.dependent_variable.single_acceleration_norm(
        propagation_setup.acceleration.point_mass_gravity_type, "Delfi-C3",␣
 ↪"Mars"
    ),
    propagation_setup.dependent_variable.single_acceleration_norm(
        propagation_setup.acceleration.point_mass_gravity_type, "Delfi-C3",␣
 ↪"Venus"
    ),
    propagation_setup.dependent_variable.single_acceleration_norm(
        propagation_setup.acceleration.spherical_harmonic_gravity_type,␣
 ↪"Delfi-C3", "Earth"
    ),
    propagation_setup.dependent_variable.single_acceleration_norm(
        propagation_setup.acceleration.aerodynamic_type, "Delfi-C3", "Earth"
    ),
    propagation_setup.dependent_variable.single_acceleration_norm(
        propagation_setup.acceleration.cannonball_radiation_pressure_type,␣
 ↪"Delfi-C3", "Sun"
    )
    ]


# Create propagation settings.
propagator_settings = propagation_setup.propagator.translational(
    central_bodies,
    acceleration_models,
    bodies_to_propagate,
    initial_state,
    simulation_end_epoch,
    output_variables = dependent_variables_to_save
)
# Create numerical integrator settings.
fixed_step_size = 10.0
```

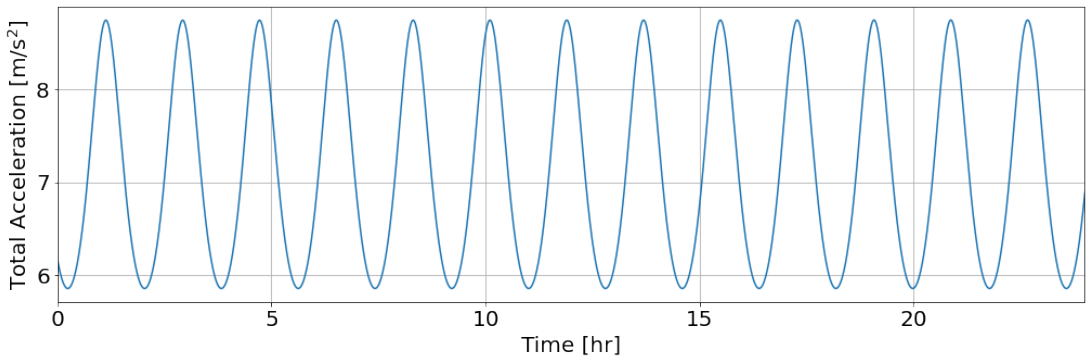
```
integrator_settings = propagation_setup.integrator.runge_kutta_4(
    simulation_start_epoch,
    fixed_step_size
)

################################################################################
# PROPAGATE ORBIT ##############################################################
################################################################################

# Create simulation object and propagate dynamics.
dynamics_simulator = propagation_setup.SingleArcDynamicsSimulator(
    bodies, integrator_settings, propagator_settings)
states = dynamics_simulator.state_history
dependent_variables = dynamics_simulator.dependent_variable_history

################################################################################
# PRINT INITIAL AND FINAL STATES ###############################################
################################################################################

print(
    f"""
Single Earth-Orbiting Satellite Example.
The initial position vector of Delfi-C3 is [km]: \n{
    states[simulation_start_epoch][:3] / 1E3}
The initial velocity vector of Delfi-C3 is [km/s]: \n{
    states[simulation_start_epoch][3:] / 1E3}
After {simulation_end_epoch} seconds the position vector of Delfi-C3 is [km]:␣
 ↪\n{
    states[simulation_end_epoch][:3] / 1E3}
And the velocity vector of Delfi-C3 is [km/s]: \n{
    states[simulation_end_epoch][3:] / 1E3}
    """
)
```

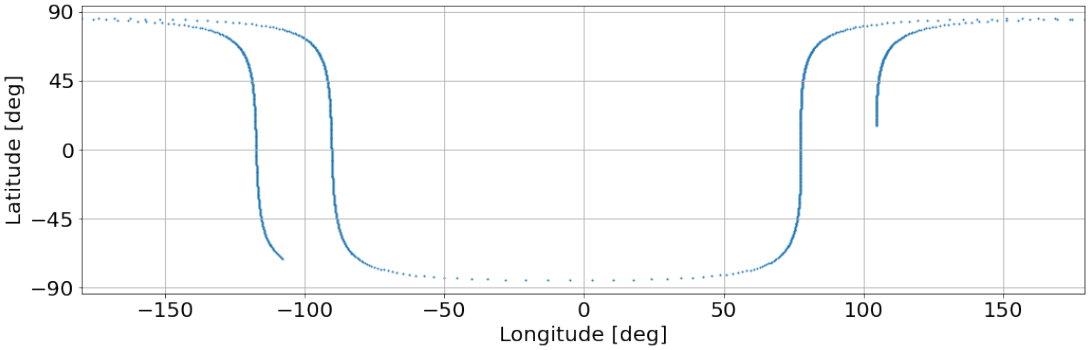
```
Single Earth-Orbiting Satellite Example.
The initial position vector of Delfi-C3 is [km]:
[7037.48400133 3238.05901792 2150.7241875 ]
The initial velocity vector of Delfi-C3 is [km/s]:
[-1.46565763 -0.04095839  6.62279761]
After 86400.0 seconds the position vector of Delfi-C3 is [km]:
[-4602.79426676 -1421.16740978  5883.69740624]
And the velocity vector of Delfi-C3 is [km/s]:
[-4.53846052 -2.36988263 -5.04163195]
```

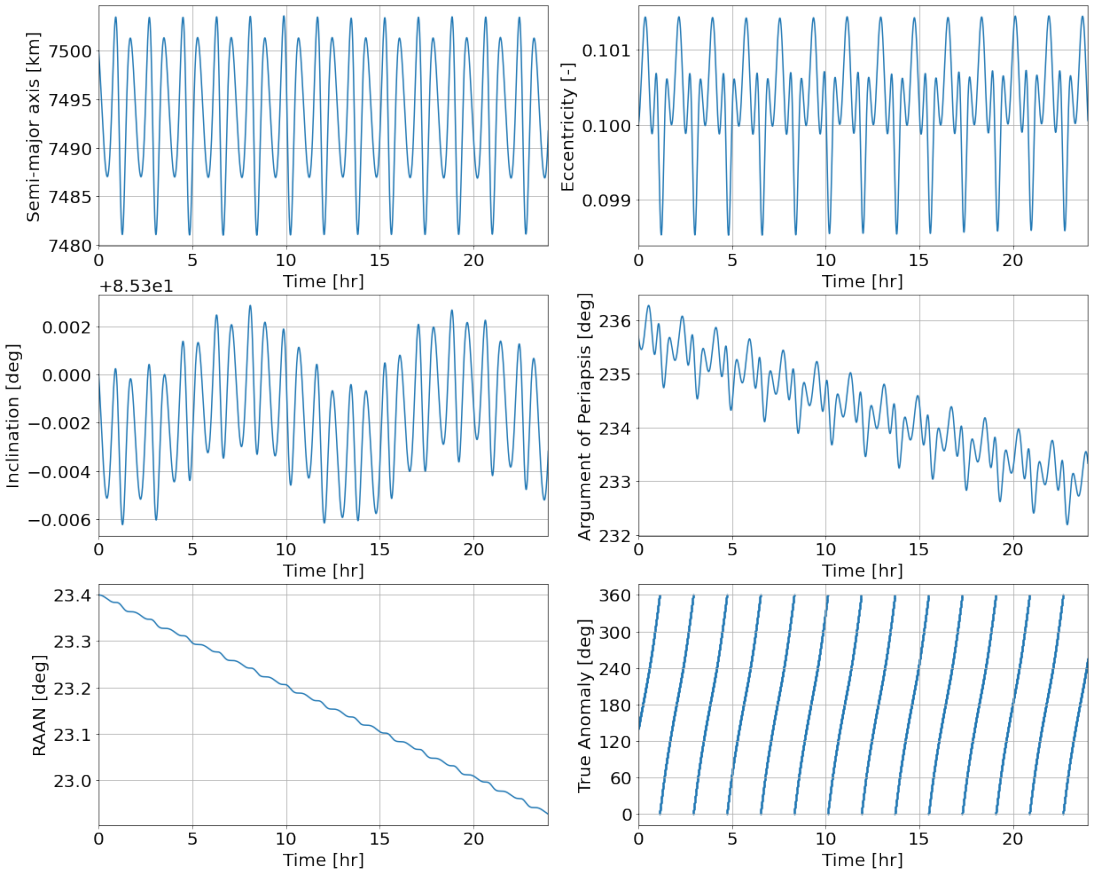
[3]:
```
import os
from matplotlib import pyplot as plt

time = dependent_variables.keys()
dependent_variable_list = np.vstack(list(dependent_variables.values()))
font_size = 20

plt.rcParams.update({'font.size': font_size})

# dependent variables
# 0-2: total acceleration
# 3-8: Keplerian state
# 9: latitude
# 10: longitude
# 11: Acceleration Norm PM Sun
# 12: Acceleration Norm PM Moon
# 13: Acceleration Norm PM Mars
# 14: Acceleration Norm PM Venus
# 15: Acceleration Norm SH Earth

total_acceleration = np.sqrt( dependent_variable_list[:,0] ** 2 +␣
 ↪dependent_variable_list[:,1] ** 2 + dependent_variable_list[:,2] ** 2 )

time_hours = [ t / 3600 for t in time]
# Total Acceleration
plt.figure( figsize=(17,5))
plt.grid()
plt.plot( time_hours , total_acceleration )
plt.xlabel('Time [hr]')
plt.ylabel( 'Total Acceleration [m/s$^2$]')
plt.xlim( [min(time_hours), max(time_hours)] )
plt.savefig( fname = f'{latex_image_path}total_acceleration.png',␣
 ↪bbox_inches='tight')



# Ground Track
latitude = dependent_variable_list[:,9]
longitude = dependent_variable_list[:,10]

part = int(len(time)/24*3)
latitude = np.rad2deg( latitude[0:part] )
longitude = np.rad2deg( longitude[0:part] )
plt.figure( figsize=(17,5))
plt.grid()
plt.yticks(np.arange(-90, 91, step=45))
plt.scatter( longitude, latitude, s=1 )
```

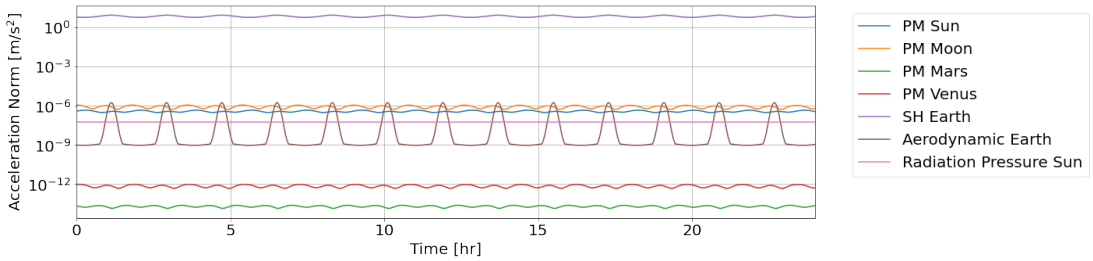
```
plt.xlabel('Longitude [deg]')
plt.ylabel( 'Latitude [deg]')
plt.xlim( [min(longitude), max(longitude)] )
plt.savefig( fname = f'{latex_image_path}ground_track.png', bbox_inches='tight')

# Kepler Elements
kepler_elements = dependent_variable_list[:,3:9]

fig, ((ax1, ax2), (ax3, ax4), (ax5, ax6)) = plt.subplots( 3, 2, figsize =␣
↪(20,17) )

# Semi-major Axis
semi_major_axis = [ element/1000 for element in kepler_elements[:,0] ]
ax1.plot( time_hours, semi_major_axis )
ax1.set_ylabel( 'Semi-major axis [km]' )

# Eccentricity
eccentricity = kepler_elements[:,1]
ax2.plot( time_hours, eccentricity )
ax2.set_ylabel( 'Eccentricity [-]' )

# Inclination
inclination = [ np.rad2deg( element ) for element in kepler_elements[:,2] ]
ax3.plot( time_hours, inclination )
ax3.set_ylabel( 'Inclination [deg]')

# Argument of Periapsis
argument_of_periapsis = [ np.rad2deg( element ) for element in kepler_elements[:
↪,3] ]
ax4.plot( time_hours, argument_of_periapsis )
ax4.set_ylabel( 'Argument of Periapsis [deg]' )

# Right Ascension of the Ascending Node
raan = [ np.rad2deg( element ) for element in kepler_elements[:,4] ]
ax5.plot( time_hours, raan )
ax5.set_ylabel( 'RAAN [deg]' )

# True Anomaly
true_anomaly = [ np.rad2deg( element ) for element in kepler_elements[:,5] ]
ax6.scatter( time_hours, true_anomaly, s=1 )
ax6.set_ylabel( 'True Anomaly [deg]' )
ax6.set_yticks(np.arange(0, 361, step=60))

for ax in fig.get_axes():
    ax.set_xlabel('Time [hr]')
    ax.set_xlim( [min(time_hours), max(time_hours)] )
    ax.grid()
```

```
plt.savefig( fname = f'{latex_image_path}kepler_elements.png',␣
 ↪bbox_inches='tight')

plt.figure( figsize=(17,5))

# Point Mass Gravity Acceleration Sun
acceleration_norm_pm_sun = dependent_variable_list[:, 11]
plt.plot( time_hours, acceleration_norm_pm_sun, label='PM Sun')

# Point Mass Gravity Acceleration Moon
acceleration_norm_pm_moon = dependent_variable_list[:, 12]
plt.plot( time_hours, acceleration_norm_pm_moon, label='PM Moon')

# Point Mass Gravity Acceleration Mars
acceleration_norm_pm_mars = dependent_variable_list[:, 13]
plt.plot( time_hours, acceleration_norm_pm_mars, label='PM Mars')

# Point Mass Gravity Acceleration Venus
acceleration_norm_pm_venus = dependent_variable_list[:, 14]
plt.plot( time_hours, acceleration_norm_pm_venus, label='PM Venus')

# Spherical Harmonic Gravity Acceleration Earth
acceleration_norm_sh_earth = dependent_variable_list[:, 15]
plt.plot( time_hours, acceleration_norm_sh_earth, label='SH Earth')

# Aerodynamic Acceleration Earth
acceleration_norm_aero_earth = dependent_variable_list[:, 16]
plt.plot( time_hours, acceleration_norm_aero_earth, label='Aerodynamic Earth')

# Cannonball Radiation Pressure Acceleration Sun
acceleration_norm_rp_sun = dependent_variable_list[:, 17]
plt.plot( time_hours, acceleration_norm_rp_sun, label='Radiation Pressure Sun')

plt.grid()
plt.legend( bbox_to_anchor=(1.04,1) )
plt.xlim( [min(time_hours), max(time_hours)])
plt.yscale('log')
plt.xlabel( 'Time [hr]' )
plt.ylabel( 'Acceleration Norm [m/s$^2$]' )

plt.savefig( fname = f'{latex_image_path}acceleration_norms.png',␣
 ↪bbox_inches='tight')
#plt.savefig('acceleration_norms.png', bbox_inches='tight')
```


Total Acceleration [m/s^2]
8
7
6
0
5
10
15
20
Time [hr]


90
45
0
−45
−90
Latitude [deg]
−150
−100
−50
0
50
100
150
Longitude [deg]


Semi-major axis [km]
7500
7495
7490
7485
7480
0
5
10
15
20
Time [hr]
Eccentricity [-]
0.101
0.100
0.099
Time [hr]
+8.53e1
Inclination [deg]
0.002
0.000
−0.002
−0.004
−0.006
Time [hr]
Argument of Periapsis [deg]
236
235
234
233
232
Time [hr]
RAAN [deg]
23.4
23.3
23.2
23.1
23.0
Time [hr]
True Anomaly [deg]
360
300
240
180
120
60
0
Time [hr]


Acceleration Norm [m/s²]
10⁰
10⁻³
10⁻⁶
10⁻⁹
10⁻¹²
0
5
10
15
20
Time [hr]
PM Sun
PM Moon
PM Mars
PM Venus
SH Earth
Aerodynamic Earth
Radiation Pressure Sun

[ ]:

G Appendix test_add.pdf

AE4868_example_notebook_update20201025

December 26, 2020

[1]:
```
def addThree(input_nr):
    '''returns the input integer plus 3, used to verify unit test'''
    return input_nr + 3
```

[2]:
```
##############################################################################
# IMPORT STATEMENTS ##########################################################
##############################################################################
import os
import numpy as np
from tudatpy.kernel import constants
from tudatpy.kernel.interface import spice_interface
from tudatpy.kernel.simulation import environment_setup
from tudatpy.kernel.simulation import propagation_setup
from tudatpy.kernel.astro import conversion

# Set path to latex image folders for project 1
latex_image_path = 'latex/project1/Images/'

# Load spice kernels.
spice_interface.load_standard_kernels()

# Set simulation start and end epochs.
simulation_start_epoch = 0.0
simulation_end_epoch = constants.JULIAN_DAY

##############################################################################
# CREATE ENVIRONMENT #########################################################
##############################################################################

# Create default body settings for selected celestial bodies
bodies_to_create = ["Sun", "Earth", "Moon", "Mars", "Venus"]

# Create default body settings for bodies_to_create, with "Earth"/"J2000" as
# global frame origin and orientation. This environment will only be valid
# in the indicated time range
# [simulation_start_epoch --- simulation_end_epoch]
body_settings = environment_setup.get_default_body_settings(
```

```
    bodies_to_create,
    simulation_start_epoch,
    simulation_end_epoch,
    "Earth","J2000")

# Create system of selected celestial bodies
bodies = environment_setup.create_system_of_bodies(body_settings)

################################################################################
# CREATE VEHICLE ###############################################################
################################################################################

# Create vehicle objects.
bodies.create_empty_body( "Delfi-C3" )
bodies.get_body( "Delfi-C3").set_constant_mass(400.0)

# Create aerodynamic coefficient interface settings, and add to vehicle
reference_area = 4.0
drag_coefficient = 1.2
aero_coefficient_settings = environment_setup.aerodynamic_coefficients.constant(
    reference_area,[drag_coefficient,0,0]
)
environment_setup.add_aerodynamic_coefficient_interface(
            bodies, "Delfi-C3", aero_coefficient_settings )

# Create radiation pressure settings, and add to vehicle
reference_area_radiation = 4.0
radiation_pressure_coefficient = 1.2
occulting_bodies = ["Earth"]
radiation_pressure_settings = environment_setup.radiation_pressure.cannonball(
    "Sun", reference_area_radiation, radiation_pressure_coefficient,␣
 ↪occulting_bodies
)
environment_setup.add_radiation_pressure_interface(
            bodies, "Delfi-C3", radiation_pressure_settings )

################################################################################
# CREATE ACCELERATIONS #########################################################
################################################################################

# Define bodies that are propagated.
bodies_to_propagate = ["Delfi-C3"]

# Define central bodies.
central_bodies = ["Earth"]

# Define accelerations acting on Delfi-C3 by Sun and Earth.
```

```
accelerations_settings_delfi_c3 = dict(
    Sun=
    [
        propagation_setup.acceleration.cannonball_radiation_pressure(),
        propagation_setup.acceleration.point_mass_gravity()
    ],
    Earth=
    [
        propagation_setup.acceleration.spherical_harmonic_gravity(5, 5),
        propagation_setup.acceleration.aerodynamic()
    ])

# Define point mass accelerations acting on Delfi-C3 by all other bodies.
for other in set(bodies_to_create).difference({"Sun", "Earth"}):
    accelerations_settings_delfi_c3[other] = [
        propagation_setup.acceleration.point_mass_gravity()]

# Create global accelerations settings dictionary.
acceleration_settings = {"Delfi-C3": accelerations_settings_delfi_c3}

# Create acceleration models.
acceleration_models = propagation_setup.create_acceleration_models(
    bodies,
    acceleration_settings,
    bodies_to_propagate,
    central_bodies)

###########################################################################
# CREATE PROPAGATION SETTINGS #############################################
###########################################################################

# Set initial conditions for the Asterix satellite that will be
# propagated in this simulation. The initial conditions are given in
# Keplerian elements and later on converted to Cartesian elements.
earth_gravitational_parameter = bodies.get_body( "Earth" ).
 ↪gravitational_parameter
initial_state = conversion.keplerian_to_cartesian(
    gravitational_parameter=earth_gravitational_parameter,
    semi_major_axis=7500.0E3,
    eccentricity=0.1,
    inclination=np.deg2rad(85.3),
    argument_of_periapsis=np.deg2rad(235.7),
    longitude_of_ascending_node=np.deg2rad(23.4),
    true_anomaly=np.deg2rad(139.87)
)

# Define list of dependent variables to save.
```

```
dependent_variables_to_save = [
    propagation_setup.dependent_variable.total_acceleration( "Delfi-C3" ),
    propagation_setup.dependent_variable.keplerian_state( "Delfi-C3", "Earth" ),
    propagation_setup.dependent_variable.latitude( "Delfi-C3", "Earth" ),
    propagation_setup.dependent_variable.longitude( "Delfi-C3", "Earth"),
    propagation_setup.dependent_variable.single_acceleration_norm(
        propagation_setup.acceleration.point_mass_gravity_type, "Delfi-C3",␣
 ↪"Sun"
    ),
    propagation_setup.dependent_variable.single_acceleration_norm(
        propagation_setup.acceleration.point_mass_gravity_type, "Delfi-C3",␣
 ↪"Moon"
    ),
    propagation_setup.dependent_variable.single_acceleration_norm(
        propagation_setup.acceleration.point_mass_gravity_type, "Delfi-C3",␣
 ↪"Mars"
    ),
    propagation_setup.dependent_variable.single_acceleration_norm(
        propagation_setup.acceleration.point_mass_gravity_type, "Delfi-C3",␣
 ↪"Venus"
    ),
    propagation_setup.dependent_variable.single_acceleration_norm(
        propagation_setup.acceleration.spherical_harmonic_gravity_type,␣
 ↪"Delfi-C3", "Earth"
    ),
    propagation_setup.dependent_variable.single_acceleration_norm(
        propagation_setup.acceleration.aerodynamic_type, "Delfi-C3", "Earth"
    ),
    propagation_setup.dependent_variable.single_acceleration_norm(
        propagation_setup.acceleration.cannonball_radiation_pressure_type,␣
 ↪"Delfi-C3", "Sun"
    )
    ]


# Create propagation settings.
propagator_settings = propagation_setup.propagator.translational(
    central_bodies,
    acceleration_models,
    bodies_to_propagate,
    initial_state,
    simulation_end_epoch,
    output_variables = dependent_variables_to_save
)
# Create numerical integrator settings.
fixed_step_size = 10.0
```

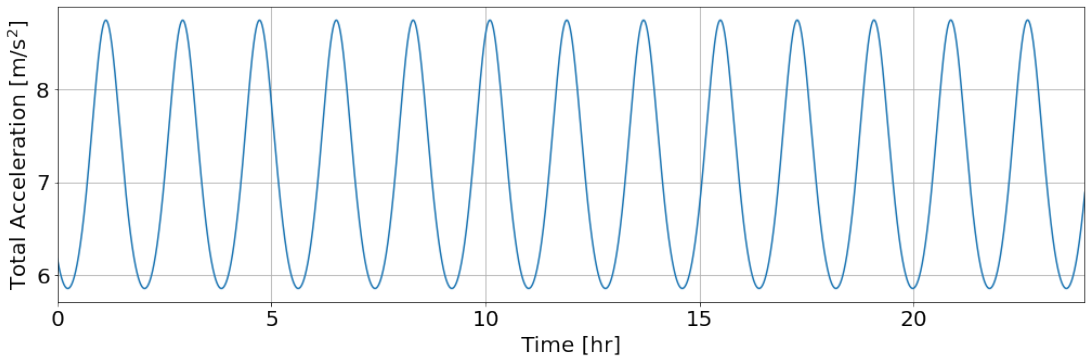
```
integrator_settings = propagation_setup.integrator.runge_kutta_4(
    simulation_start_epoch,
    fixed_step_size
)

################################################################################
# PROPAGATE ORBIT ##############################################################
################################################################################

# Create simulation object and propagate dynamics.
dynamics_simulator = propagation_setup.SingleArcDynamicsSimulator(
    bodies, integrator_settings, propagator_settings)
states = dynamics_simulator.state_history
dependent_variables = dynamics_simulator.dependent_variable_history

################################################################################
# PRINT INITIAL AND FINAL STATES ###############################################
################################################################################

print(
    f"""
Single Earth-Orbiting Satellite Example.
The initial position vector of Delfi-C3 is [km]: \n{
    states[simulation_start_epoch][:3] / 1E3}
The initial velocity vector of Delfi-C3 is [km/s]: \n{
    states[simulation_start_epoch][3:] / 1E3}
After {simulation_end_epoch} seconds the position vector of Delfi-C3 is [km]:␣
 ↪\n{
    states[simulation_end_epoch][:3] / 1E3}
And the velocity vector of Delfi-C3 is [km/s]: \n{
    states[simulation_end_epoch][3:] / 1E3}
    """
)
```

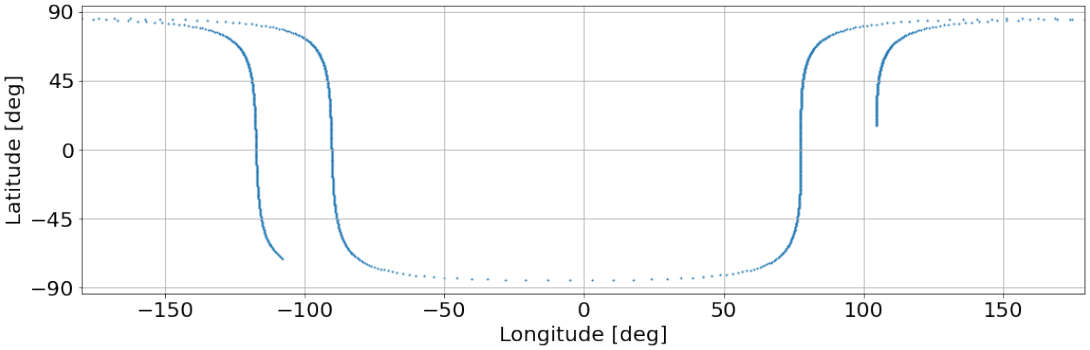
```
Single Earth-Orbiting Satellite Example.
The initial position vector of Delfi-C3 is [km]:
[7037.48400133 3238.05901792 2150.7241875 ]
The initial velocity vector of Delfi-C3 is [km/s]:
[-1.46565763 -0.04095839  6.62279761]
After 86400.0 seconds the position vector of Delfi-C3 is [km]:
[-4602.79426676 -1421.16740978  5883.69740624]
And the velocity vector of Delfi-C3 is [km/s]:
[-4.53846052 -2.36988263 -5.04163195]
```

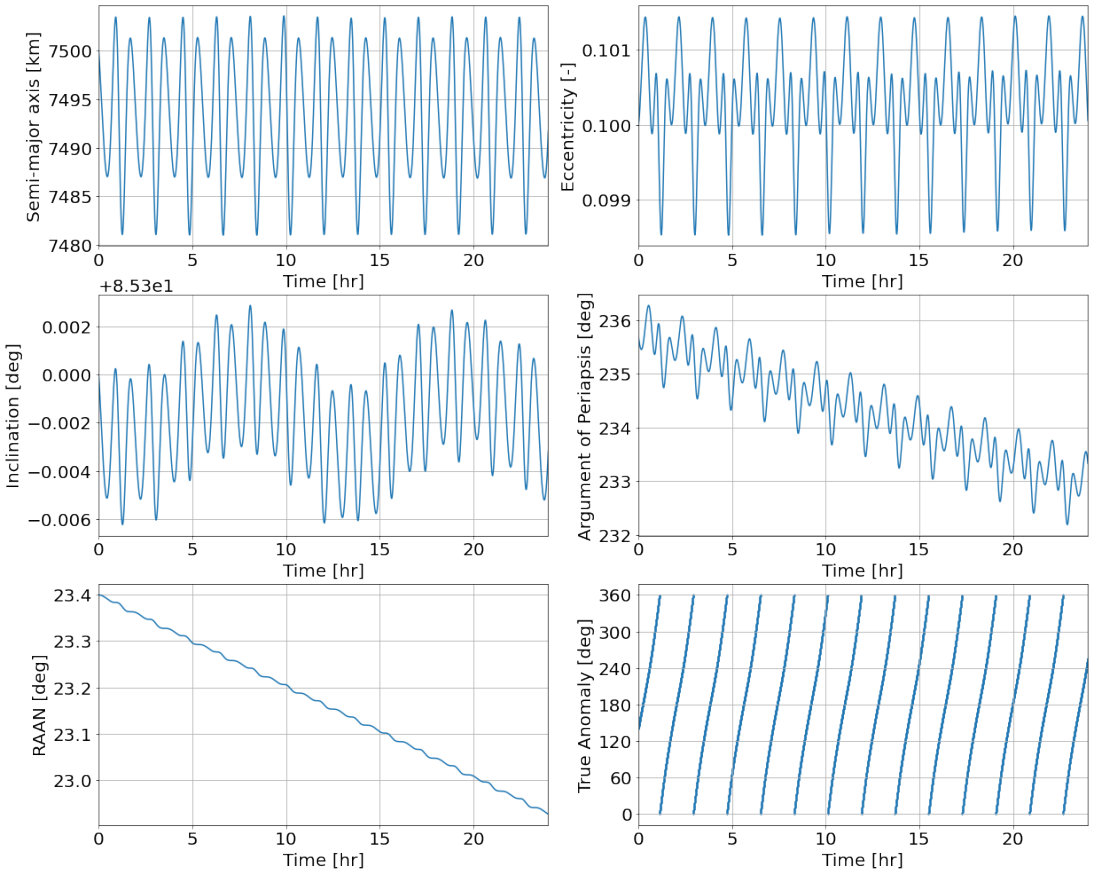
[3]:
```
import os
from matplotlib import pyplot as plt

time = dependent_variables.keys()
dependent_variable_list = np.vstack(list(dependent_variables.values()))
font_size = 20

plt.rcParams.update({'font.size': font_size})

# dependent variables
# 0-2: total acceleration
# 3-8: Keplerian state
# 9: latitude
# 10: longitude
# 11: Acceleration Norm PM Sun
# 12: Acceleration Norm PM Moon
# 13: Acceleration Norm PM Mars
# 14: Acceleration Norm PM Venus
# 15: Acceleration Norm SH Earth

total_acceleration = np.sqrt( dependent_variable_list[:,0] ** 2 +␣
 ↪dependent_variable_list[:,1] ** 2 + dependent_variable_list[:,2] ** 2 )

time_hours = [ t / 3600 for t in time]
# Total Acceleration
plt.figure( figsize=(17,5))
plt.grid()
plt.plot( time_hours , total_acceleration )
plt.xlabel('Time [hr]')
plt.ylabel( 'Total Acceleration [m/s$^2$]')
plt.xlim( [min(time_hours), max(time_hours)] )
plt.savefig( fname = f'{latex_image_path}total_acceleration.png',␣
 ↪bbox_inches='tight')



# Ground Track
latitude = dependent_variable_list[:,9]
longitude = dependent_variable_list[:,10]

part = int(len(time)/24*3)
latitude = np.rad2deg( latitude[0:part] )
longitude = np.rad2deg( longitude[0:part] )
plt.figure( figsize=(17,5))
plt.grid()
plt.yticks(np.arange(-90, 91, step=45))
plt.scatter( longitude, latitude, s=1 )
```

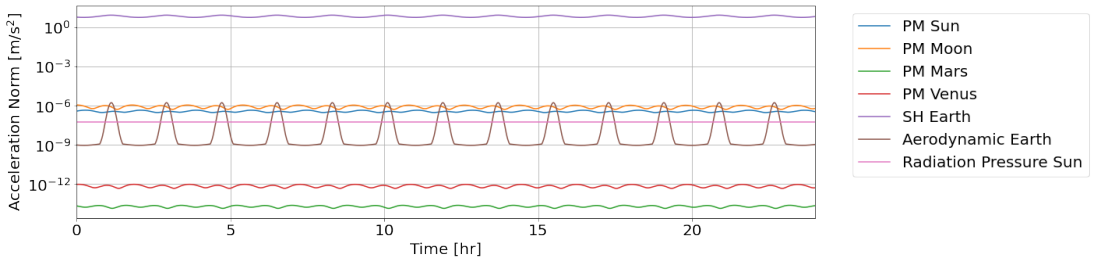
```
plt.xlabel('Longitude [deg]')
plt.ylabel( 'Latitude [deg]')
plt.xlim( [min(longitude), max(longitude)] )
plt.savefig( fname = f'{latex_image_path}ground_track.png', bbox_inches='tight')

# Kepler Elements
kepler_elements = dependent_variable_list[:,3:9]

fig, ((ax1, ax2), (ax3, ax4), (ax5, ax6)) = plt.subplots( 3, 2, figsize =␣
↪(20,17) )

# Semi-major Axis
semi_major_axis = [ element/1000 for element in kepler_elements[:,0] ]
ax1.plot( time_hours, semi_major_axis )
ax1.set_ylabel( 'Semi-major axis [km]' )

# Eccentricity
eccentricity = kepler_elements[:,1]
ax2.plot( time_hours, eccentricity )
ax2.set_ylabel( 'Eccentricity [-]' )

# Inclination
inclination = [ np.rad2deg( element ) for element in kepler_elements[:,2] ]
ax3.plot( time_hours, inclination )
ax3.set_ylabel( 'Inclination [deg]')

# Argument of Periapsis
argument_of_periapsis = [ np.rad2deg( element ) for element in kepler_elements[:
↪,3] ]
ax4.plot( time_hours, argument_of_periapsis )
ax4.set_ylabel( 'Argument of Periapsis [deg]' )

# Right Ascension of the Ascending Node
raan = [ np.rad2deg( element ) for element in kepler_elements[:,4] ]
ax5.plot( time_hours, raan )
ax5.set_ylabel( 'RAAN [deg]' )

# True Anomaly
true_anomaly = [ np.rad2deg( element ) for element in kepler_elements[:,5] ]
ax6.scatter( time_hours, true_anomaly, s=1 )
ax6.set_ylabel( 'True Anomaly [deg]' )
ax6.set_yticks(np.arange(0, 361, step=60))

for ax in fig.get_axes():
    ax.set_xlabel('Time [hr]')
    ax.set_xlim( [min(time_hours), max(time_hours)] )
    ax.grid()
```

```
plt.savefig( fname = f'{latex_image_path}kepler_elements.png',␣
 ↪bbox_inches='tight')

plt.figure( figsize=(17,5))

# Point Mass Gravity Acceleration Sun
acceleration_norm_pm_sun = dependent_variable_list[:, 11]
plt.plot( time_hours, acceleration_norm_pm_sun, label='PM Sun')

# Point Mass Gravity Acceleration Moon
acceleration_norm_pm_moon = dependent_variable_list[:, 12]
plt.plot( time_hours, acceleration_norm_pm_moon, label='PM Moon')

# Point Mass Gravity Acceleration Mars
acceleration_norm_pm_mars = dependent_variable_list[:, 13]
plt.plot( time_hours, acceleration_norm_pm_mars, label='PM Mars')

# Point Mass Gravity Acceleration Venus
acceleration_norm_pm_venus = dependent_variable_list[:, 14]
plt.plot( time_hours, acceleration_norm_pm_venus, label='PM Venus')

# Spherical Harmonic Gravity Acceleration Earth
acceleration_norm_sh_earth = dependent_variable_list[:, 15]
plt.plot( time_hours, acceleration_norm_sh_earth, label='SH Earth')

# Aerodynamic Acceleration Earth
acceleration_norm_aero_earth = dependent_variable_list[:, 16]
plt.plot( time_hours, acceleration_norm_aero_earth, label='Aerodynamic Earth')

# Cannonball Radiation Pressure Acceleration Sun
acceleration_norm_rp_sun = dependent_variable_list[:, 17]
plt.plot( time_hours, acceleration_norm_rp_sun, label='Radiation Pressure Sun')

plt.grid()
plt.legend( bbox_to_anchor=(1.04,1) )
plt.xlim( [min(time_hours), max(time_hours)])
plt.yscale('log')
plt.xlabel( 'Time [hr]' )
plt.ylabel( 'Acceleration Norm [m/s$^2$]' )

plt.savefig( fname = f'{latex_image_path}acceleration_norms.png',␣
 ↪bbox_inches='tight')
#plt.savefig('acceleration_norms.png', bbox_inches='tight')
```


Total Acceleration [m/s^2]
8
7
6
0
5
10
15
20
Time [hr]


90
45
0
−45
−90
Latitude [deg]
−150
−100
−50
0
50
100
150
Longitude [deg]


Semi-major axis [km]
7500
7495
7490
7485
7480
0
5
10
15
20
Time [hr]
Eccentricity [-]
0.101
0.100
0.099
Time [hr]
+8.53e1
Inclination [deg]
0.002
0.000
−0.002
−0.004
−0.006
Time [hr]
Argument of Periapsis [deg]
236
235
234
233
232
Time [hr]
RAAN [deg]
23.4
23.3
23.2
23.1
23.0
Time [hr]
True Anomaly [deg]
360
300
240
180
120
60
0
Time [hr]


Acceleration Norm [m/s²]
10⁰
10⁻³
10⁻⁶
10⁻⁹
10⁻¹²
0
5
10
15
20
Time [hr]
PM Sun
PM Moon
PM Mars
PM Venus
SH Earth
Aerodynamic Earth
Radiation Pressure Sun

[ ]: