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 **??**.

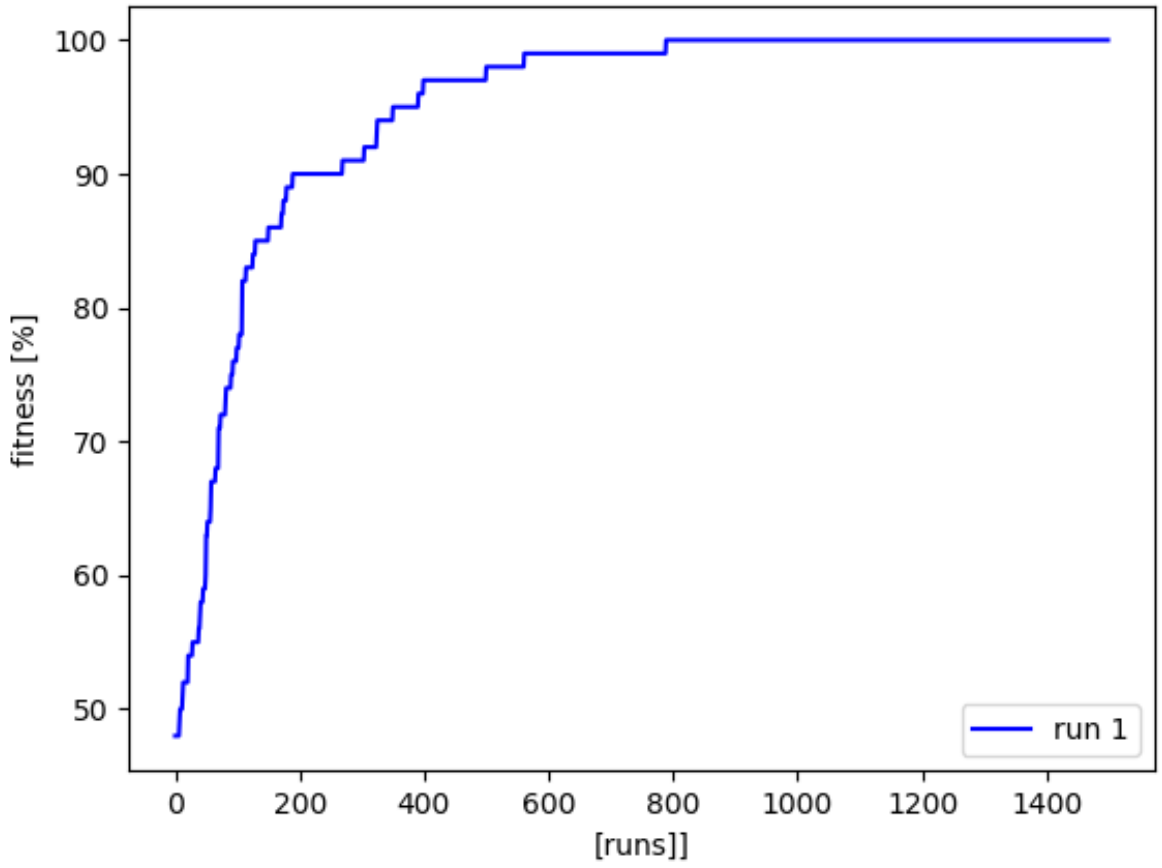


Figure 1: Performance of some genetic algorithm

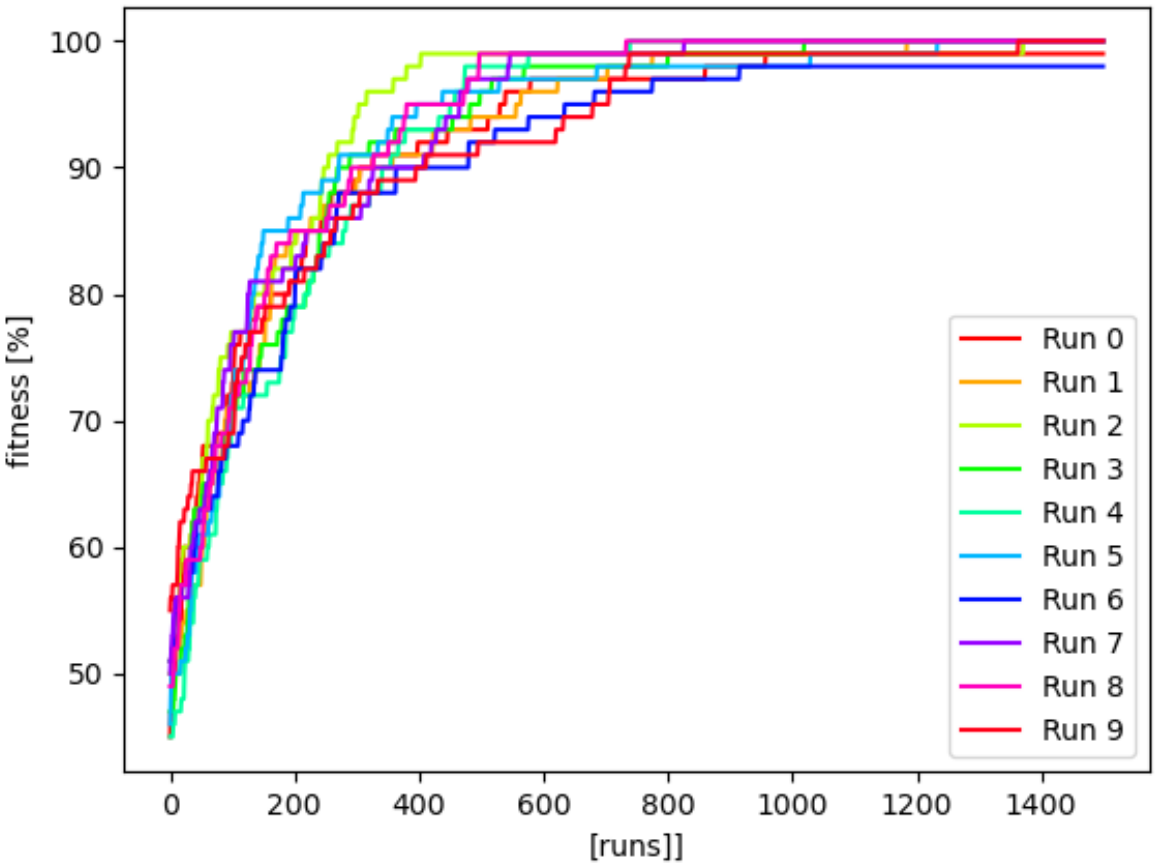


Figure 2: Performance of some genetic algorithm

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

```python
# 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):
    """This function exports the python files and compiled pdfs of jupiter notebooks into the
    latex of the same project number. First it scans which appendices (without code, without
    notebooks) are already manually included in the main latex code. Next, all appendices
    that contain the python code are eiter found or created in the following order:
    First, the __main__.py file is included, followed by the main.py file, followed by all
    python code files in alphabetic order. After this, all the pdfs of the compiled notebooks
    are added in alphabetic order of filename. This order of appendices is overwritten in the
    main tex file.

    :param main_latex_filename: Name of the main latex document of this project number
    :param project_nr: The number  indicating which project this code pertains to.
    """
    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')

```

```
35      created_python_appendix_filenames = create_appendices_with_code(
           ↪ appendix_dir, missing_python_files_in_appendices, '.py',
           ↪ project_nr, root_dir)
36      created_notebook_appendix_filenames = create_appendices_with_code
           ↪ (appendix_dir, missing_notebook_files_in_appendices, '.
           ↪ ipynb', project_nr, root_dir)
37
38      appendices = get_list_of_appendix_files(appendix_dir,
           ↪ compiled_notebook_pdf_filepaths, python_filepaths)
39
40      main_tex_code, start_index, end_index, appendix_tex_code =
           ↪ get_appendix_tex_code(path_to_main_latex_file)
41      # assumes non-included non-code appendices should not be included
           ↪ :
42      non_code_appendices, main_non_code_appendix_inclusion_lines =
           ↪ get_order_of_non_code_appendices_in_main(appendices,
           ↪ appendix_tex_code)
43
44      python_appendix_filenames = list(map(lambda x: x.
           ↪ appendix_filename, filter_appendices_by_type(appendices, '
           ↪ python')))
45      sorted_created_python_appendices = sort_python_appendices(
           ↪ filter_appendices_by_type(appendices, 'python'))
46      sorted_python_appendix_filenames = list(map(lambda x: x.
           ↪ appendix_filename, sorted_created_python_appendices))
47
48      notebook_appendix_filenames = list(map(lambda x: x.
           ↪ appendix_filename, filter_appendices_by_type(appendices, '
           ↪ notebook')))
49      sorted_created_notebook_appendices =
           ↪ sort_notebook_appendices_alphabetically(
           ↪ filter_appendices_by_type(appendices, 'notebook'))
50      sorted_notebook_appendix_filenames = list(map(lambda x: x.
           ↪ appendix_filename, sorted_created_notebook_appendices))
51
52      appendix_latex_code = create_appendices_latex_code(
           ↪ main_non_code_appendix_inclusion_lines,
           ↪ sorted_created_notebook_appendices, project_nr,
           ↪ sorted_created_python_appendices)
53
54      updated_main_tex_code = substitute_appendix_code(end_index,
           ↪ main_tex_code, start_index, appendix_latex_code)
55
56      overwrite_content_to_file(updated_main_tex_code,
           ↪ path_to_main_latex_file)
57
58
59  def create_appendices_latex_code(
       ↪ main_non_code_appendix_inclusion_lines, notebook_appendices,
       ↪ project_nr, python_appendices):
60      """Creates the latex code that includeds the appendices in the
           ↪ main latex file.
61
62      :param main_non_code_appendix_inclusion_lines: latex code that
           ↪ includes the appendices that do not contain python code nor
           ↪  notebooks
63      :param notebook_appendices: List of Appendix objects representing
           ↪  appendices that include the pdf files of compiled Jupiter
           ↪ notebooks
64      :param project_nr: The number indicating which project this code
           ↪ pertains to.
```

```
    :param python_appendices: List of Appendix objects representing
       ↪ appendices that include the python code files.
    """
    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 all appendices of a certain appendix type,
       ↪  from the incoming list of Appendix objects.

    :param appendices: List of Appendix objects
    :param appendix_type: Can consist of "no_code", "python", or "
       ↪ notebook" and indicates different appendix types
    """
    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: List of Appendix objects
    """
    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 = sort_appendices_on_code_filename(
       ↪ filtered_remaining_appendices)
    return return_appendices+appendices_sorted_a_z


def sort_notebook_appendices_alphabetically(appendices):
```

```
    """Sorts notebook appendix objects alphabetic order of their pdf filenames.

    :param appendices: List of Appendix objects
    """
    return_appendices = []
    filtered_remaining_appendices = [i for i in appendices if i.code_filename is not None]
    appendices_sorted_a_z = sort_appendices_on_code_filename(filtered_remaining_appendices)
    return return_appendices+appendices_sorted_a_z


def sort_appendices_on_code_filename(appendices):
    """Returns a list of Appendix objects that are sorted and  based on the property: code_filename.
    Assumes the incoming appendices only contain python files.

    :param appendices: List of Appendix objects
    """
    attributes = list(map(lambda x: x.code_filename, appendices))
    sorted_indices = sorted(range(len(attributes)), key=lambda k: attributes[k])
    sorted_list = []
    for i in sorted_indices:
        sorted_list.append(appendices[i])
    return sorted_list


def get_order_of_non_code_appendices_in_main(appendices, appendix_tex_code):
    """Scans the lines of appendices in the main code, and returns the lines
    of the appendices that do not contain code, in the order in which they were
    included in the main latex file.

    :param appendices: List of Appendix objects
    :param appendix_tex_code: latex code from the main latex file that includes the appendices
    """
    non_code_appendices = []
    non_code_appendix_lines = []
    appendix_tex_code = list(dict.fromkeys(appendix_tex_code))
    for line in appendix_tex_code:
        appendix_filename = get_filename_from_latex_appendix_line(appendices, line)

        # Check if line is not commented
        if not appendix_filename is None:
            if not line_is_commented(line,appendix_filename):
                appendix = get_appendix_from_filename(appendices, appendix_filename)
                if appendix.appendix_type == "no_code":
                    non_code_appendices.append(appendix)
                    non_code_appendix_lines.append(line)
    return non_code_appendices, non_code_appendix_lines


def get_filename_from_latex_appendix_line(appendices, appendix_line):
    """Returns the first filename from a list of incoming filenames that
```

```
164     occurs in a latex code line.
165 
166     :param appendices: List of Appendix objects
167     :param appendix_line: latex code (in particular expected to be
          ↪ the code from main that is used to include appendix latex
          ↪ files.)
168     """
169     for filename in list(map(lambda appendix: appendix.
          ↪ appendix_filename, appendices)):
170         if filename in appendix_line:
171             if not line_is_commented(appendix_line, filename):
172                 return filename
173 
174 
175 def get_appendix_from_filename(appendices, appendix_filename):
176     """Returns the first Appendix object with an appendix filename
          ↪ that matches the incoming appendix_filename.
177     The Appendix objects are selected from an incoming list of
          ↪ Appendix objects.
178 
179     :param appendices: List of Appendix objects
180     :param appendix_filename: name of a latex appendix file, ends in
          ↪ .tex,
181     """
182     for appendix in appendices:
183         if appendix_filename == appendix.appendix_filename:
184             return appendix
185 
186 
187 def get_compiled_notebook_paths(script_dir):
188     """Returns the list of jupiter notebook filepaths that were
          ↪ compiled successfully and that are
189     included in the same dias this script (the src directory).
190 
191     :param script_dir: absolute path of this file.
192     """
193     notebook_filepaths= get_filenames_in_dir('.ipynb', script_dir)
194     compiled_notebook_filepaths = []
195 
196     # check if the jupyter notebooks were compiled
197     for notebook_filepath in notebook_filepaths:
198 
199         # swap file extension
200         notebook_filepath = notebook_filepath.replace('.ipynb','.pdf'
              ↪ )
201 
202         # check if file exists
203         if os.path.isfile(notebook_filepath):
204             compiled_notebook_filepaths.append(notebook_filepath)
205     return compiled_notebook_filepaths
206 
207 
208 def get_list_of_appendix_files(appendix_dir,
      ↪ absolute_notebook_filepaths, absolute_python_filepaths):
209     """Returns a list of Appendix objects that contain all the
          ↪ appendix files with .tex extension.
210 
211     :param appendix_dir: Absolute path that contains the appendix .
          ↪ tex files.
212     :param absolute_notebook_filepaths: List of absolute paths to the
          ↪  compiled notebook pdf files.
```

```
    :param absolute_python_filepaths: List of absolute paths to the
       ↪ python files.
    """
    appendices = []
    appendices_paths = get_filenames_in_dir('.tex', appendix_dir)

    for appendix_filepath in appendices_paths:
        appendix_type = "no_code"
        appendix_filecontent = read_file(appendix_filepath)
        line_nr_python_file_inclusion = get_line_of_latex_command(
           ↪ appendix_filecontent, "\pythonexternal{")
        line_nr_notebook_file_inclusion = get_line_of_latex_command(
           ↪ appendix_filecontent, "\includepdf[pages=")
        if  line_nr_python_file_inclusion > -1:
            appendix_type = "python"
            # get python filename
            line = appendix_filecontent[line_nr_python_file_inclusion
               ↪ ]
            filename = get_filename_from_latex_inclusion_command(line
               ↪ , '.py', "\pythonexternal{")
            appendices.append(Appendix(appendix_filepath,
               ↪ appendix_filecontent, appendix_type, filename, line
               ↪ ))
        if line_nr_notebook_file_inclusion > -1:
            appendix_type = "notebook"
            line = appendix_filecontent[
               ↪ line_nr_notebook_file_inclusion]
            filename = get_filename_from_latex_inclusion_command(
               ↪ line, '.pdf', "\includepdf[pages=")
            appendices.append(Appendix(appendix_filepath,
               ↪ appendix_filecontent, appendix_type, filename, line
               ↪ ))
        else:
            appendices.append(Appendix(appendix_filepath,
               ↪ appendix_filecontent, appendix_type))
    return appendices


def get_filename_from_latex_inclusion_command(appendix_line,
   ↪ extension, start_substring):
    """returns the code/notebook filename in a latex command which
       ↪ includes that code in an appendix.
    The inclusion command includes a python code or jupiter notebook
       ↪ pdf.

    :param appendix_line: :Line of latex code (in particular expected
       ↪  to be the latex code from an appendix.).
    :param extension: The file extension of the file that is sought
       ↪ in the appendix line. Either ".py" or ".pdf".
    :param start_substring: The substring that characterises the
       ↪ latex inclusion command.
    """
    start_index = appendix_line.index(start_substring)
    end_index = appendix_line.index(extension)
    return get_filename_from_dir(appendix_line[start_index:end_index+
       ↪ len(extension)])


def get_filenames_in_dir(extension, path, excluded_files=None):
    """Returns a list of the relative paths to all files within the
       ↪ some path that match
    the given file extension.
```

```
255
256     :param extension: The file extension of the file that is sought
            ↪ in the appendix line. Either ".py" or ".pdf".
257     :param path: Absolute filepath in which files are being sought.
258     :param excluded_files: (Default value = None) Files that will not
            ↪  be included even if they are found.
        """
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_code_filepaths, appendix_dir, extension, project_nr,
        ↪ root_dir):
270     """Returns a list of code filepaths that are already properly
            ↪ included the latex appendix files of this project.
271
272     :param absolute_code_filepaths: List of absolute paths to the
            ↪ code files (either python files or compiled jupyter
            ↪ notebook pdfs).
273     :param appendix_dir: Absolute path that contains the appendix .
            ↪ tex files.
274     :param extension: The file extension of the file that is sought
            ↪ in the appendix line. Either ".py" or ".pdf".
275     :param project_nr: The number  indicating which project this code
            ↪  pertains to.
276     :param root_dir: The root directory of this repository.
277     """
278     appendix_files = get_filenames_in_dir('.tex', appendix_dir)
279     contained_codes = []
280     for code_filepath in absolute_code_filepaths:
281         for appendix_filepath in appendix_files:
282             appendix_filecontent = read_file(appendix_filepath)
283             line_nr = check_if_appendix_contains_file(
                    ↪ appendix_filecontent, code_filepath, extension,
                    ↪ project_nr, root_dir)
284             if line_nr>-1:
285                 # add filepath to list of files that are already in
                        ↪ the appendices
286                 contained_codes.append(Appendix_with_code(
                        ↪ code_filepath,
287                 appendix_filepath,
288                 appendix_filecontent,
289                 line_nr,
290                 '.py'))
291     return contained_codes
292
293
294 def check_if_appendix_contains_file(appendix_content, code_filepath,
        ↪ extension, project_nr, root_dir):
295     """Scans an appendix content to determine whether it contains a
            ↪ substring that
296     includes a code file (of either python or compiled notebook=pdf
            ↪ extension).
297
298     :param appendix_content: content in an appendix latex file.
```

```
299     :param code_filepath: Absolute path to a code file (either python
            ↪  files or compiled jupyter notebook pdfs).
300     :param extension: The file extension of the file that is sought
            ↪ in the appendix line. Either ".py" or ".pdf".
301     :param project_nr: The number  indicating which project this code
            ↪  pertains to.
302     :param root_dir: The root directory of this repository.
303     """
304     # convert code_filepath to the inclusion format in latex format
305     latex_relative_filepath = f'latex/project{project_nr}/../../{
            ↪ code_filepath[len(root_dir):]}'
306     latex_command = get_latex_inclusion_command(extension,
            ↪ latex_relative_filepath)
307     return get_line_of_latex_command(appendix_content, latex_command)
308
309
310 def get_line_of_latex_command(appendix_content, latex_command):
311     """Returns the line number of a latex command if it is found.
            ↪ Returns -1 otherwise.
312
313     :param appendix_content: content in an appendix latex file.
314     :param latex_command: A line of latex code. (Expected to come
            ↪ from some appendix)
315     """
316     # check if the file is in the latex code
317     line_nr = 0
318     for line in appendix_content:
319         if latex_command in line:
320             if line_is_commented(line,latex_command):
321                 commented=True
322             else:
323                 return line_nr
324         line_nr=line_nr+1
325     return -1
326
327
328 def line_is_commented(line, target_substring):
329     """Returns True if a latex code line is commented, returns False
            ↪ otherwise
330
331     :param line: A line of latex code that contains a relevant
            ↪ command (target substring).
332     :param target_substring: Used to determine whether the command
            ↪ that is found is commented or not.
333     """
334     left_of_command = line[:line.rfind(target_substring)]
335     if '%' in left_of_command:
336         return True
337     return False
338
339
340 def get_latex_inclusion_command(extension,
        ↪ latex_relative_filepath_to_codefile):
341     """Creates and returns a latex command that includes either a
            ↪ python file or a compiled jupiter
342     notebook pdf (whereever the command is placed). The command is
            ↪ intended to be placed in the appendix.
343
344     :param extension: The file extension of the file that is sought
            ↪ in the appendix line. Either ".py" or ".pdf".
345     :param latex_relative_filepath_to_codefile: The latex compilation
            ↪  requires a relative path towards code files
```

```
346     that are included. Therefore, a relative path towards the code is
          ↪ given.
347 
348     """
349     if extension==".py":
350         left = "\pythonexternal{"
351         right = "}"
352         latex_command = f'{left}{latex_relative_filepath_to_codefile
              ↪ }{right}'
353     elif extension==".ipynb":
354 
355         left = "\includepdf[pages=-]{"
356         right = "}"
357         latex_command = f'{left}{latex_relative_filepath_to_codefile
              ↪ }{right}'
358     return latex_command
359 
360 
361 def read_file(filepath):
362     """Reads content of a file and returns it as a list of strings
363 
364     :param filepath:
365 
366     """
367     with open(filepath) as f:
368         content = f.readlines()
369     return content
370 
371 
372 def get_code_files_not_yet_included_in_appendices(code_filepaths,
      ↪ contained_codes, extension):
373     """Returns a list of filepaths that are not yet properly included
          ↪ in some appendix of this projectX,
374 
375     :param code_filepaths:
376     :param contained_codes:
377     :param extension: The file extension of the file that is sought
          ↪ in the appendix line. Either ".py" or ".pdf".
378 
379     """
380     contained_filepaths = list(map(lambda contained_file:
          ↪ contained_file.code_filepath, contained_codes))
381     not_contained = []
382     for filepath in code_filepaths:
383         if not filepath in contained_filepaths:
384             not_contained.append(filepath)
385     return not_contained
386 
387 
388 def create_appendices_with_code(appendix_dir, code_filepaths,
      ↪ extension, project_nr, root_dir):
389     """Creates the latex appendix files in with relevant codes
          ↪ included.
390 
391     :param appendix_dir:
392     :param code_filepaths:
393     :param extension: The file extension of the file that is sought
          ↪ in the appendix line. Either ".py" or ".pdf".
394     :param project_nr: The number  indicating which project this code
          ↪  pertains to.
395     :param root_dir: The root directory of this repository.
396 
```

```
397     """
398     appendix_filenames = []
399     appendix_reference_index = 0
400 
401     for code_filepath in code_filepaths:
402         latex_relative_filepath = f'latex/project{project_nr}/../../{
            ↪ code_filepath[len(root_dir):]}'
403         content = []
404         filename = get_filename_from_dir(code_filepath)
405         content = create_section(appendix_reference_index, filename,
            ↪ content)
406         inclusion_command = get_latex_inclusion_command(extension,
            ↪ latex_relative_filepath)
407         content.append(inclusion_command)
408         overwrite_content_to_file(content, f'{appendix_dir}
            ↪ Auto_generated_{extension[1:]}_App{
            ↪ appendix_reference_index}.tex', False)
409         appendix_filenames.append(f'Auto_generated_{extension[1:]}
            ↪ _App{appendix_reference_index}.tex')
410         appendix_reference_index = appendix_reference_index+1
411     return appendix_filenames
412 
413 
414 def create_section(appendix_reference_index, code_filename, content):
415     """
416 
417     :param appendix_reference_index:
418     :param code_filename:
419     :param content:
420 
421     """
422     # write section
423     left ="\section{Appendix "
424     middle = code_filename.replace("_","\_")
425     right = "}\label{app:"
426     end = "}" # TODO: update appendix reference index
427     content.append(f'{left}{middle}{right}{appendix_reference_index}{
            ↪ end}')
428     return content
429 
430 
431 def overwrite_content_to_file(content, filepath, content_has_newlines
    ↪ =True):
432     """Writes the content of an appendix to a new appendix
433 
434     :param content:
435     :param filepath:
436     :param content_has_newlines:  (Default value = True)
437 
438     """
439     with open(filepath,'w') as f:
440         for line in content:
441             if content_has_newlines:
442                 f.write(line)
443             else:
444                 f.write(line+'\n')
445 
446 
447 def get_appendix_tex_code(main_latex_filename):
448     """gets the latex appendix code from the main tex file.
449 
```

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

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

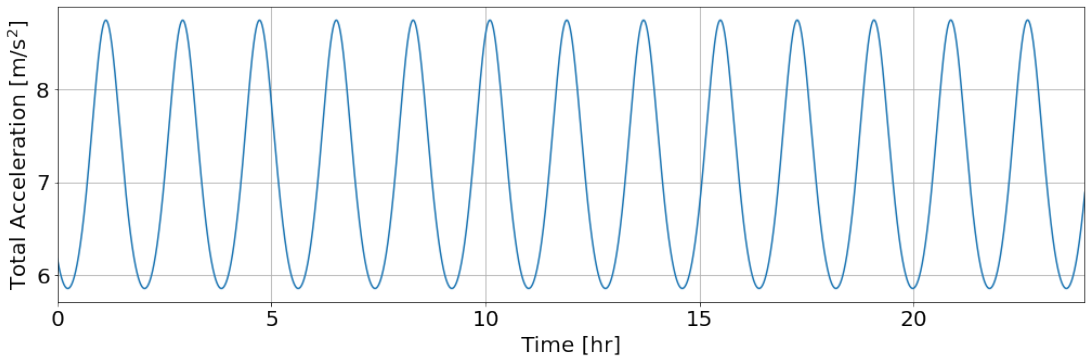
```
integrator_settings = propagation_setup.integrator.runge_kutta_4(
    simulation_start_epoch,
    fixed_step_size
)

################################################################################
# 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}
    """
)
```

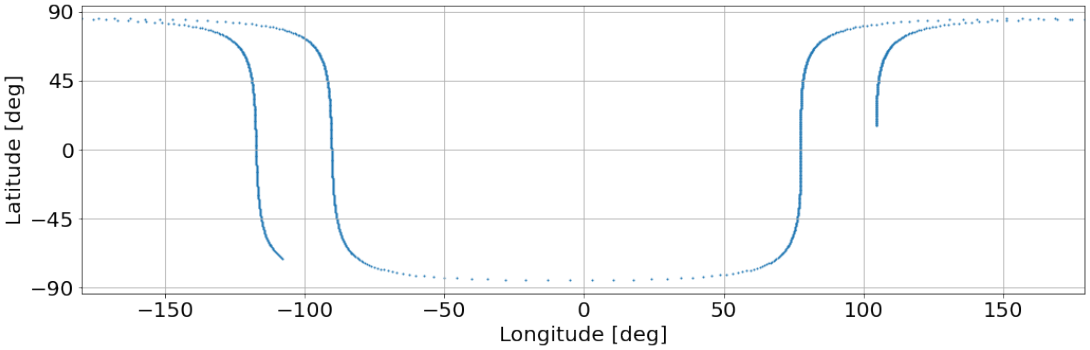
```
Single Earth-Orbiting Satellite Example.
The initial position vector of Delfi-C3 is [km]:
[7037.48400133 3238.05901792 2150.7241875 ]
The initial velocity vector of Delfi-C3 is [km/s]:
[-1.46565763 -0.04095839  6.62279761]
After 86400.0 seconds the position vector of Delfi-C3 is [km]:
[-4602.79426676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

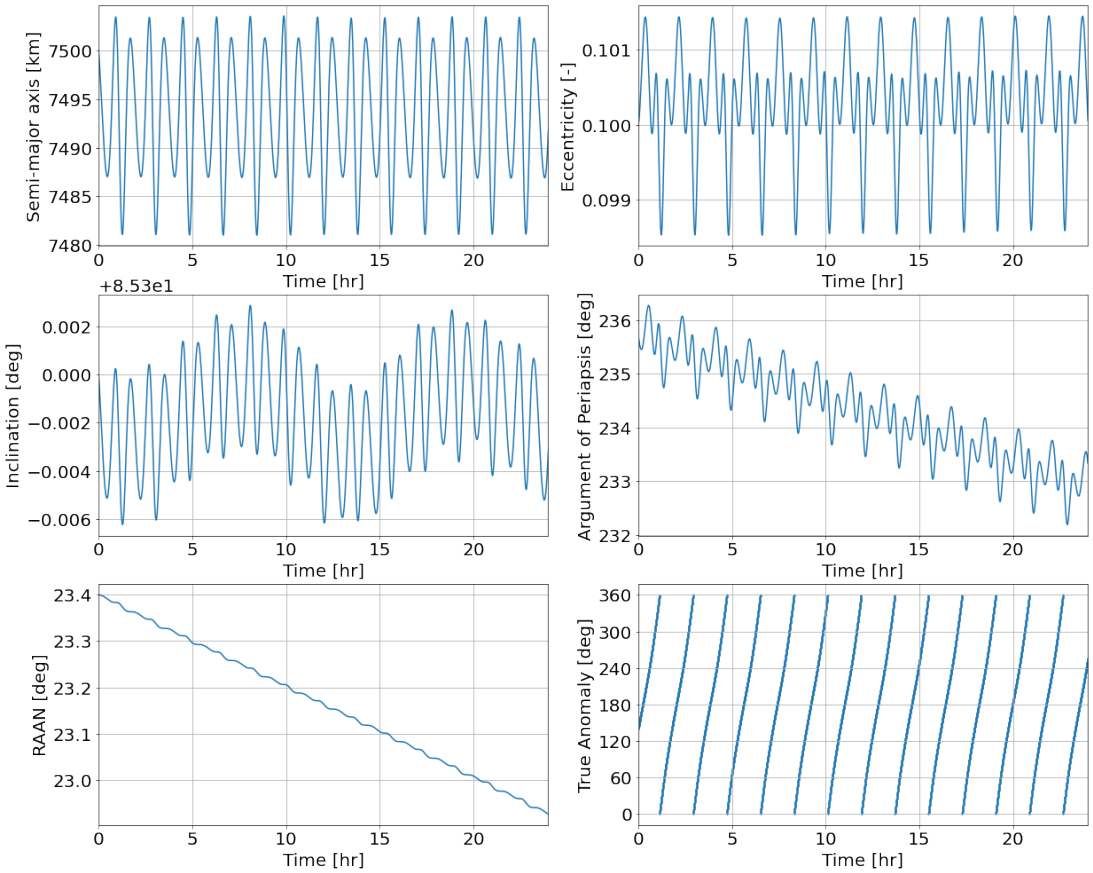
[3]:
```
import os
from matplotlib import pyplot as plt

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 )
```

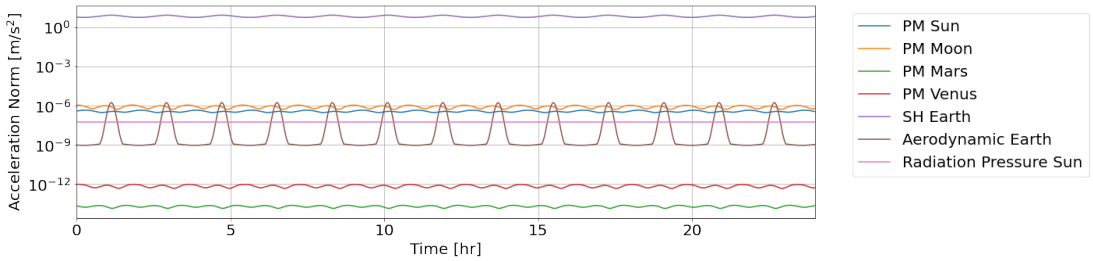
```
plt.xlabel('Longitude [deg]')
plt.ylabel( 'Latitude [deg]')
plt.xlim( [min(longitude), max(longitude)] )
plt.savefig( fname = f'{latex_image_path}ground_track.png', bbox_inches='tight')

# 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
```

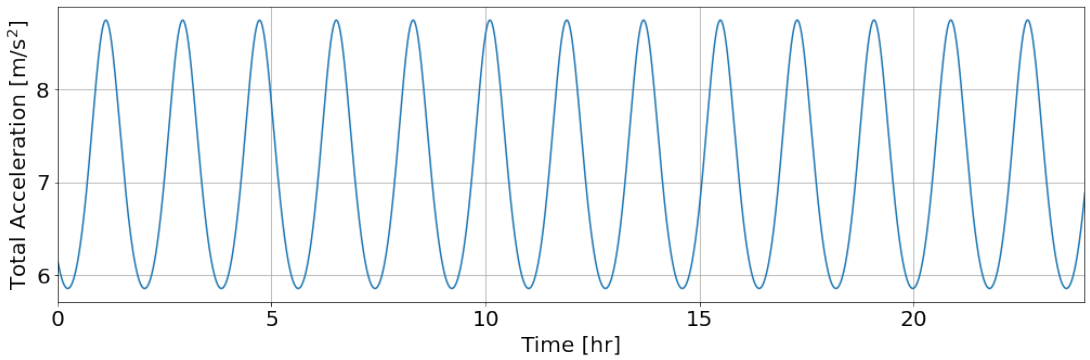
```
integrator_settings = propagation_setup.integrator.runge_kutta_4(
    simulation_start_epoch,
    fixed_step_size
)

################################################################################
# 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}
    """
)
```

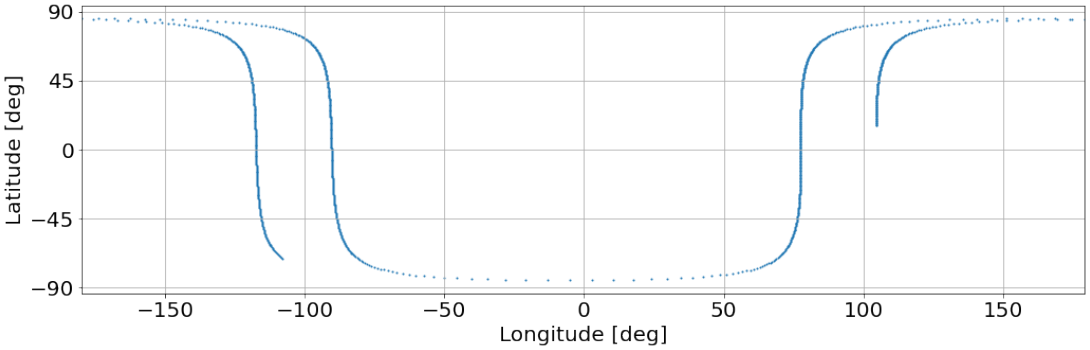
```
Single Earth-Orbiting Satellite Example.
The initial position vector of Delfi-C3 is [km]:
[7037.48400133 3238.05901792 2150.7241875 ]
The initial velocity vector of Delfi-C3 is [km/s]:
[-1.46565763 -0.04095839  6.62279761]
After 86400.0 seconds the position vector of Delfi-C3 is [km]:
[-4602.79426676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

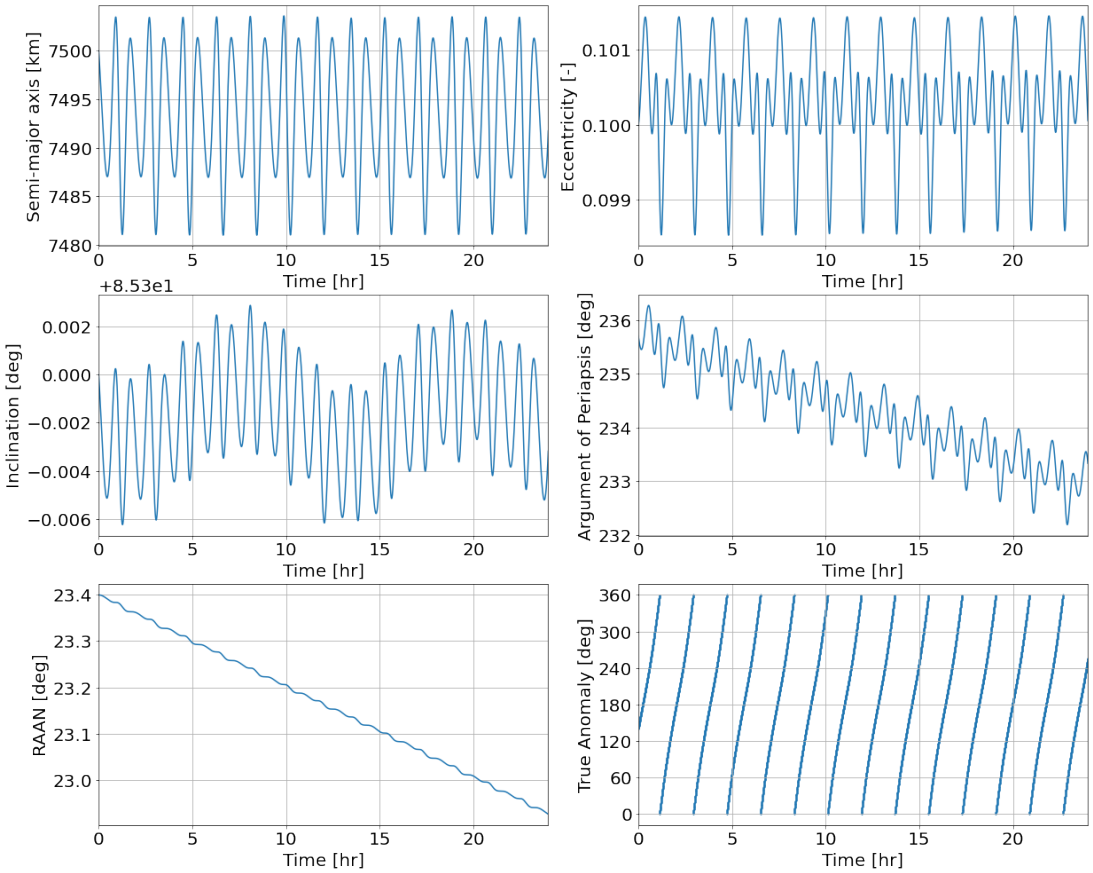
[3]:
```
import os
from matplotlib import pyplot as plt

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 )
```

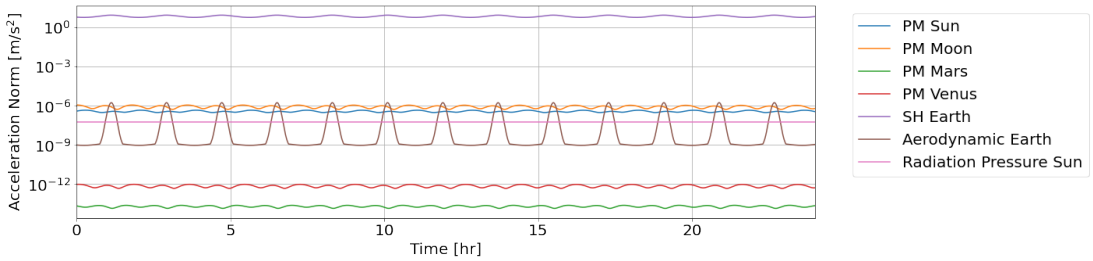
```
plt.xlabel('Longitude [deg]')
plt.ylabel( 'Latitude [deg]')
plt.xlim( [min(longitude), max(longitude)] )
plt.savefig( fname = f'{latex_image_path}ground_track.png', bbox_inches='tight')

# 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

[ ]: