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 **??**.

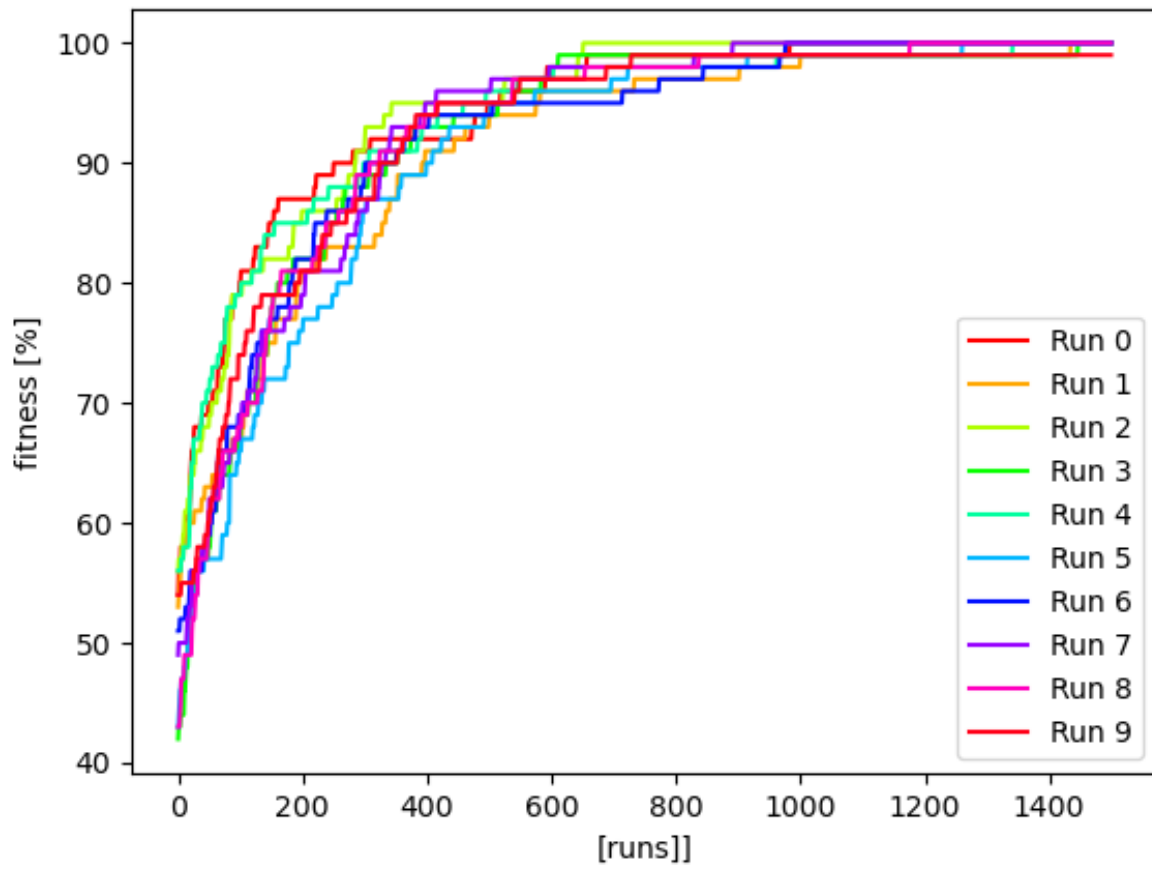Figure 1: Performance of some genetic algorithm

Figure 2: Performance of some genetic algorithm

A Appendix __main__.py

```python
1  import os
2  from .Main import Main
3
4  print(f'Hi, I\'ll be running the main code, and I\'ll let you know
      ↪  when I\'m done.')
5  project_nr = 1
6  main = Main()
7
8  notebook_names = ['AE4868_example_notebook_update20201025.ipynb']
9
10  # run the jupyter notebooks for assignment 1
11  main.run_jupyter_notebooks(project_nr,notebook_names)
12
13  # convert jupyter notebook for assignment 1 to pdf
14  main.convert_notebooks_to_pdf(project_nr,notebook_names)
15
16  # compile the latex report
17  main.compile_latex_report(project_nr)
18
19  ############################################################
20  ###########example code to illustrate python-latex  image sync
      ↪  #########
21  #############runs arbitrary genetic algorithm, can be deleted
      ↪  ###########
22  ############################################################
23  # run a genetic algorithm to create some data for a plot.
24  print("now running a")
25  res = main.do_run_a()
26
27  # plot some graph with a single line, general form is:
28  # plt_tex.plotSingleLines(plt_tex,x,y,"x-axis label","y-axis label",
      ↪  lineLabels,"filename",legend_position,project_nr)
29  # main.plt_tex.plotSingleLine(plt_tex,range(0, len(res)),res,"[runs
      ↪  ]]","fitness [%]","run 1","4a",4,project_nr)
30
31  # run a genetic algorithm to create some data for another plot.
32  print("now running b")
33  main.do4b(project_nr)
34
35  # run a genetic algorithm to create some data for another plot.
36  print("now running 4c")
37  main.do4c(project_nr)
38
39  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

# 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 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

    def gen_bit_sequence(self):
        bits = []
        for _ in range(string_length):
```

4

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

```python
117         # plt_tex.plotMultipleLines(plt_tex,x,y,"x-axis label","y-
            # ↪ axis label",lineLabels,"filename",legend_position,
            # ↪ project_nr)
118         plt_tex.plotMultipleLines(plt_tex,range(0, len(res)),
            ↪ plotResult,"[runs]]","fitness [%]",lineLabels,"4b",4,
            ↪ project_nr)
119         print("total optimum found: {} out of {} runs".format(
            ↪ optimum_found,10))

121     def do4c(self,project_nr):
122         optimum_found = 0

124         # generate plot data
125         plotResult = np.zeros((10,max_iterations+1), dtype=int);
126         lineLabels = []

128         # perform computation
129         for run in range(10):
130             res = self.do_run_c()
131             if res[-1] == string_length:
132                 optimum_found +=1

134             # Store computation results for plot
135             lineLabels.append(f'Run {run}')
136             plotResult[run,:]=res;

138         # plot multiple lines into report (res is an array of
            ↪ dataseries (representing the lines))
139         # plt_tex.plotMultipleLines(plt_tex,x,y,"x-axis label","y-
            ↪ axis label",lineLabels,"filename",legend_position,
            ↪ project_nr)
140         plt_tex.plotMultipleLines(plt_tex,range(0, len(res)),
            ↪ plotResult,"[runs]]","fitness [%]",lineLabels,"4c",4,
            ↪ project_nr)

142         print("total optimum found: {} out of {} runs".format(
            ↪ optimum_found, 10))

144     def addTwo(self,x):
145         ''' adds two to the incoming integer and returns the result
            ↪ of the computation.'''
146         return x+2

148 if __name__ == '__main__':
149     # initialize main class
150     main = Main()
```

Appendix python code that exports figures to latex

```python
### 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);
```

```python
        # generate colours
        cmap = self.get_cmap(len(y_series[:,0]))

        # generate line types
        lineTypes = self.generateLineTypes(y_series)

        for i in range(0,len(y_series)):
            # overwrite linetypes to single type
            lineTypes[i] = "-"
            ax.plot(x,y_series[i,:],ls=lineTypes[i],label=label[i],
                ↪ fillstyle='none',c=cmap(i)); # color

        # configure plot layout
        plt.legend(loc=legendPosition);
        plt.xlabel(x_label);
        plt.ylabel(y_label);
        plt.savefig(os.path.dirname(__file__)+'/../../../latex/
            ↪ project'+str(project_nr)+'/Images/'+filename+'.png');

        print(f'plotted lines')

    # Generate random line colours
    # Source: https://stackoverflow.com/questions/14720331/how-to-
        ↪ generate-random-colors-in-matplotlib
    def get_cmap(n, name='hsv'):
        '''Returns a function that maps each index in 0, 1, ..., n-1
            ↪ to a distinct
        RGB color; the keyword argument name must be a standard mpl
            ↪ colormap name.'''
        return plt.cm.get_cmap(name, n)

    def generateLineTypes(y_series):
        # generate varying linetypes
        typeOfLines = list(lines.lineStyles.keys())

        while(len(y_series)>len(typeOfLines)):
            typeOfLines.append("-.");

        # remove void lines
        for i in range(0, len(y_series)):
            if (typeOfLines[i]=='None'):
                typeOfLines[i]='-'
            if (typeOfLines[i]==''):
                typeOfLines[i]=':'
            if (typeOfLines[i]==' '):
                typeOfLines[i]='--'
        return typeOfLines

    # Create a table with: table_matrix = np.zeros((4,4),dtype=object
        ↪ ) and pass it to this object
    def put_table_in_tex(self, table_matrix,filename,project_nr):
        cols = np.shape(table_matrix)[1]
        format = "%s"
        for col in range(1,cols):
            format = format+" & %s"
        format = format+""
        plt.savetxt(os.path.dirname(__file__)+"/../../../latex/
            ↪ project"+str(project_nr)+"/tables/"+filename+".txt",
            ↪ table_matrix, delimiter=' & ', fmt=format, newline='
            ↪ \\\\ \hline \n')
```

```python
    # replace this with your own table creation and then pass it to
        put_table_in_tex(..)
    def example_create_a_table(self):
        project_nr = "1"
        table_name = "example_table_name"
        rows = 2;
        columns = 4;
        table_matrix = np.zeros((rows,columns),dtype=object)
        table_matrix[:,:]="" # replace the standard zeros with emtpy
            cell
        print(table_matrix)
        for column in range(0,columns):
            for row in range(0,rows):
                table_matrix[row,column]=row+column
        table_matrix[1,0]="example"
        table_matrix[0,1]="grid sizes"

        self.put_table_in_tex(table_matrix,table_name,project_nr)


    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 = Plot_to_tex()
    main.example_create_a_table()
```

Appendix python code that compiles the latex report to pdf

```python
# 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()
```

Appendix python code that runs the jupyter notebook(s)

```python
# 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

November 9, 2020

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

```python
[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(
```

```python
    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.
```

```python
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.
```

```python
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
```

```python
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 )
```

```python
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()
```

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```python
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')
```
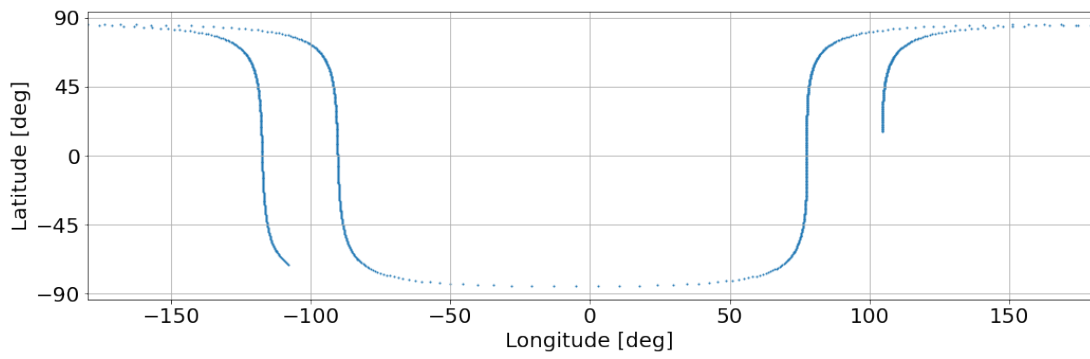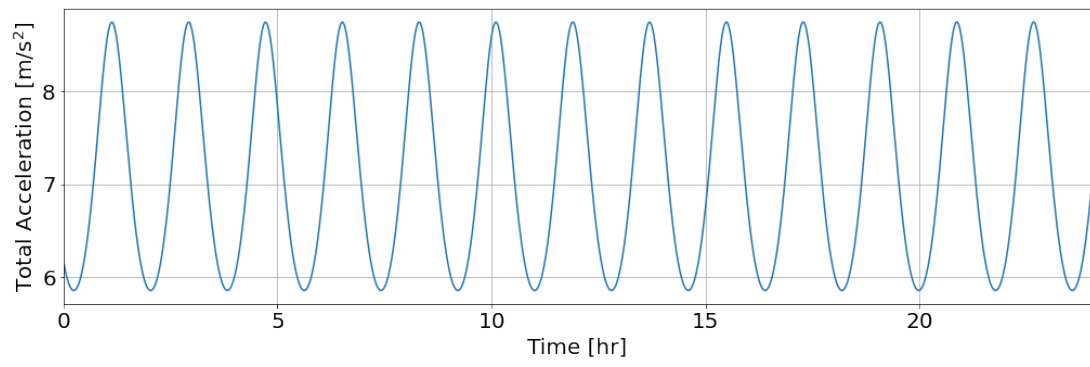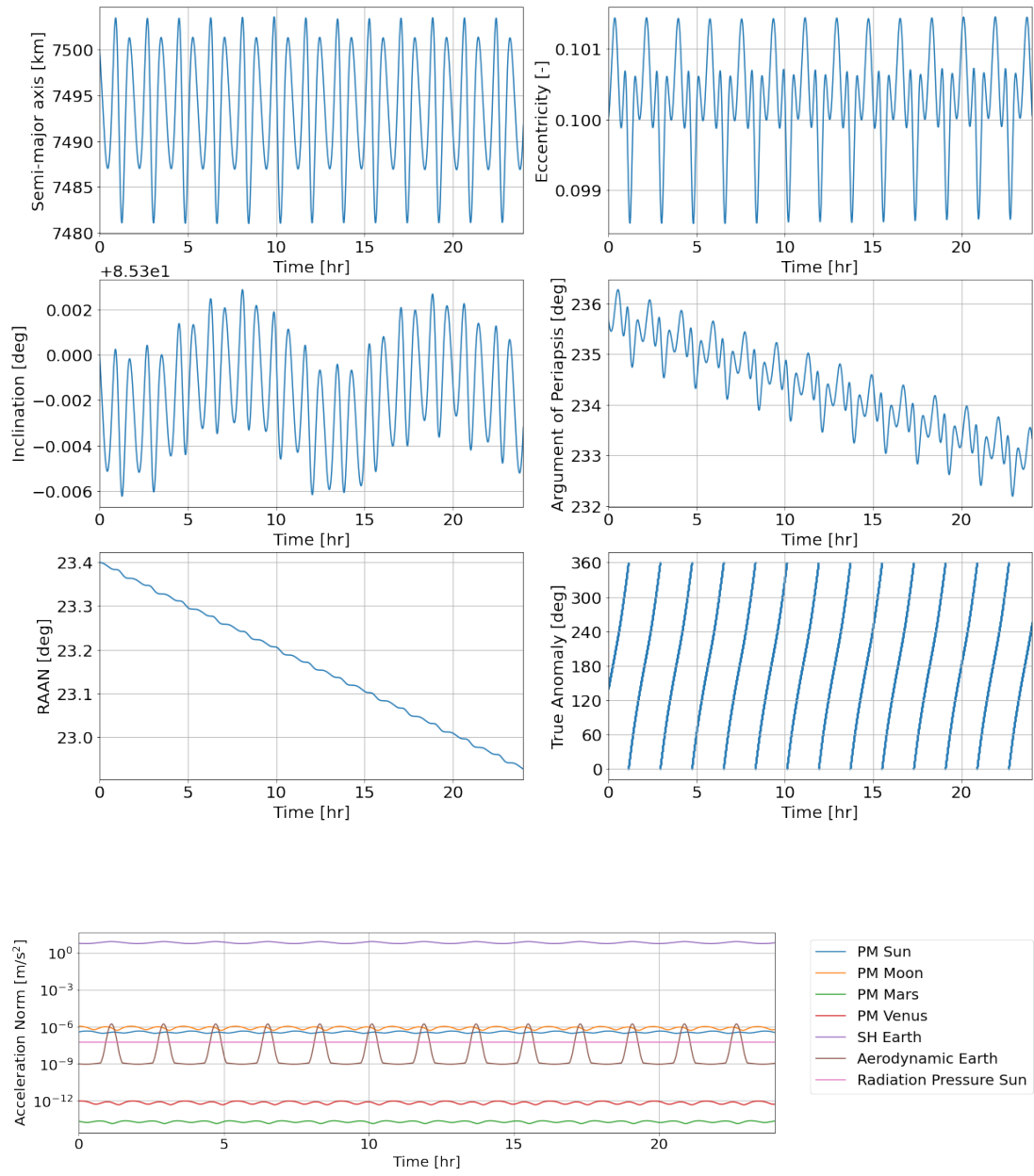
[ ]: