System Dynamics Modeling with se-lib User's Guide

April 11, 2023

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1 Introduction

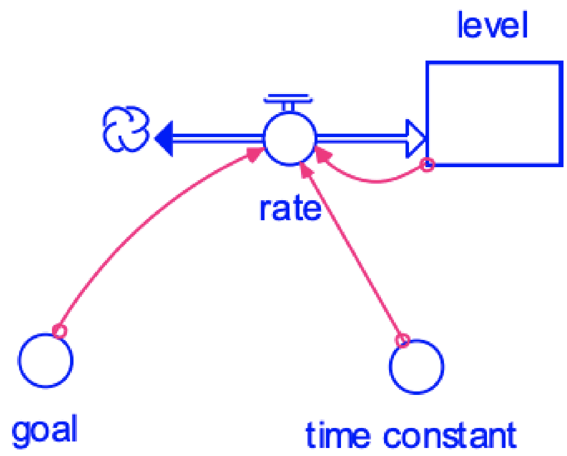
The se-lib library provides system dynamics modeling and simulation functions. It is built on top of the PySD library and internally uses the XMILE file format standard for system dynamics.

A system model is described by defining the standard elements for stocks (levels), flows (rates), and auxiliary constants or equations. Names of model elements and their equations are specified as character strings.

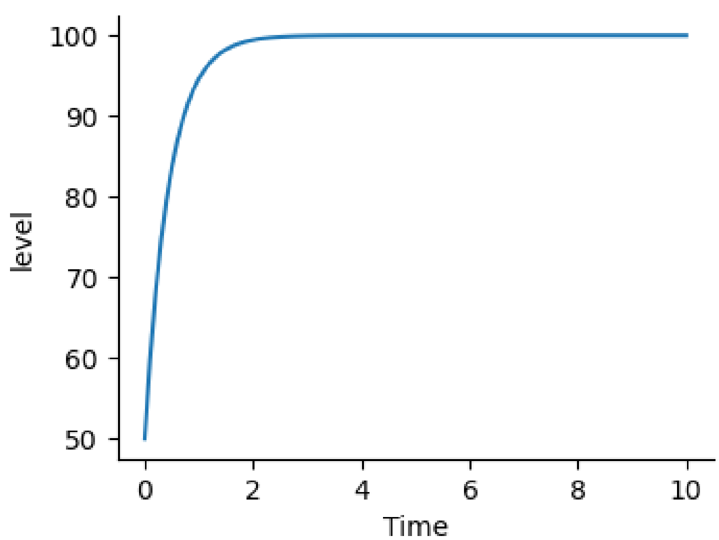
Utility functions are available for equation formulation, data collection and displaying outut. Detailed function references and examples are available online at `http://se-lib.org/function_reference.html#system-dynamics`. Examples are shown of the basic features next.

1.1 Basic Modeling Functions

The following example implements a simple first order delay structure. Before using any of the functions the se-lib library must be imported. First a model must be initialized. A stock is defined with an initial level, the flow and auxiliary variable for the delay. The model is run over time and a graph is plotted of the resulting level.

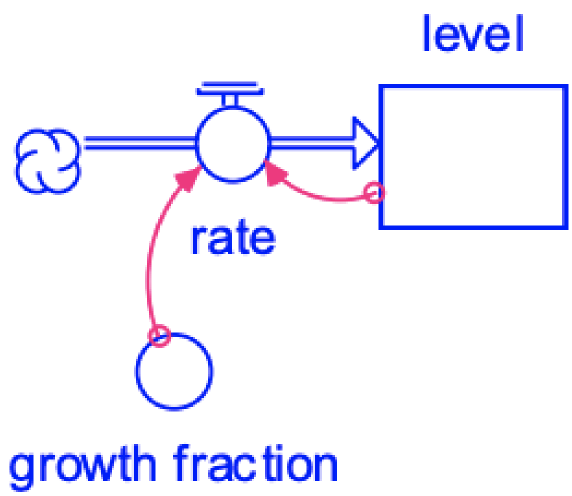


[7]:
```
# import all functions
from selib_sd import *

# negative feedback
init_model(start=0, stop=10, dt=.1)
add_stock("level", 50, inflows=["rate"])
add_auxiliary("time_constant", .5)
add_auxiliary("goal", 100)
add_flow("rate", "(goal - level) / time_constant")
run_model()

plot_graph('level')
```

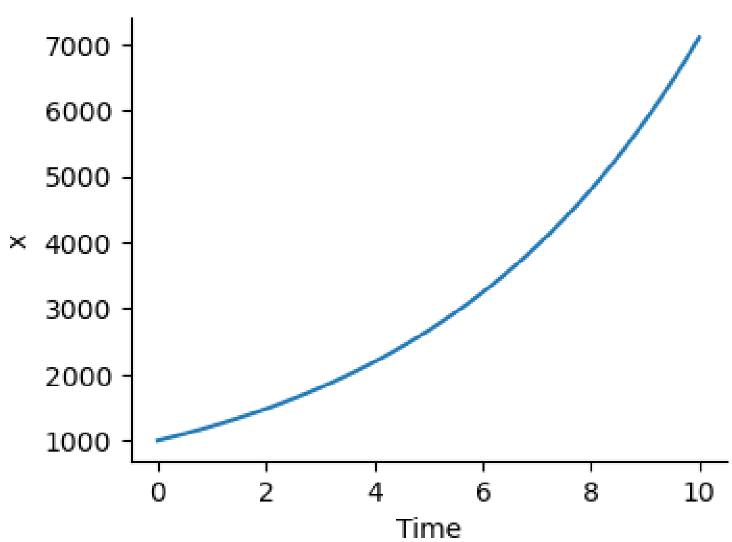


1.2 Exponential Growth

A model of exponential growth per the following structure is shown.



[25]:
```
# exponential growth

init_model(start=0, stop=10, dt=.2)

add_stock("x", 1000, inflows=["dx"])
add_flow("dx", "x*growth_factor")
add_auxiliary("growth_factor", .2)

run_model()
plot_graph('x')
```



1.3 Displaying Output

The `run_model()` function will execute a simulation and return a Pandas dataframe of the output. It can displayed by the following statements demonstrated in the program below for a Rayleigh curve.

```
output = run_model()
output
```

[18]:
```
# Rayleigh curve staffing model

init_model(start=0, stop=6, dt=.5)

add_stock("cumulative_effort", 0, inflows=["effort_rate"])
add_flow("effort_rate", "learning_function * (estimated_total_effort -␣
 ↪cumulative_effort)")
add_auxiliary("learning_function", "manpower_buildup_parameter * time")
add_auxiliary("manpower_buildup_parameter", .5)
add_auxiliary("estimated_total_effort", 15)

output = run_model()
output
```

[18]:
```
     INITIAL TIME  FINAL TIME  TIME STEP  SAVEPER  effort_rate  \
0.0             0           6        0.5      0.5     0.000000
0.5             0           6        0.5      0.5     3.750000
1.0             0           6        0.5      0.5     6.562500
1.5             0           6        0.5      0.5     7.382812
2.0             0           6        0.5      0.5     6.152344
2.5             0           6        0.5      0.5     3.845215
3.0             0           6        0.5      0.5     1.730347
3.5             0           6        0.5      0.5     0.504684
4.0             0           6        0.5      0.5     0.072098
4.5             0           6        0.5      0.5     0.000000
5.0             0           6        0.5      0.5     0.000000
5.5             0           6        0.5      0.5     0.000000
6.0             0           6        0.5      0.5     0.000000

     learning_function  manpower_buildup_parameter  estimated_total_effort  \
0.0               0.00                         0.5                      15
0.5               0.25                         0.5                      15
1.0               0.50                         0.5                      15
1.5               0.75                         0.5                      15
2.0               1.00                         0.5                      15
2.5               1.25                         0.5                      15
3.0               1.50                         0.5                      15
```

```
3.5              1.75                          0.5                       15
4.0              2.00                          0.5                       15
4.5              2.25                          0.5                       15
5.0              2.50                          0.5                       15
5.5              2.75                          0.5                       15
6.0              3.00                          0.5                       15

     cumulative_effort
0.0           0.000000
0.5           0.000000
1.0           1.875000
1.5           5.156250
2.0           8.847656
2.5          11.923828
3.0          13.846436
3.5          14.711609
4.0          14.963951
4.5          15.000000
5.0          15.000000
5.5          15.000000
6.0          15.000000
```

Specific variables can accessed using a dictionary key notation per the following:

[10]:
```
output['learning_function']
```

[10]:
```
0.0    0.00
0.5    0.25
1.0    0.50
1.5    0.75
2.0    1.00
2.5    1.25
3.0    1.50
3.5    1.75
4.0    2.00
4.5    2.25
5.0    2.50
5.5    2.75
6.0    3.00
Name: learning_function, dtype: float64
```

The value of a variable at a given time can be accessed using time as the second key index:

[17]:
```
output['learning_function'][2]
```

[17]:
```
1.0
```

Multiple variables can be provided in a list:

[13]:
```
output[['learning_function', 'cumulative_effort']]
```

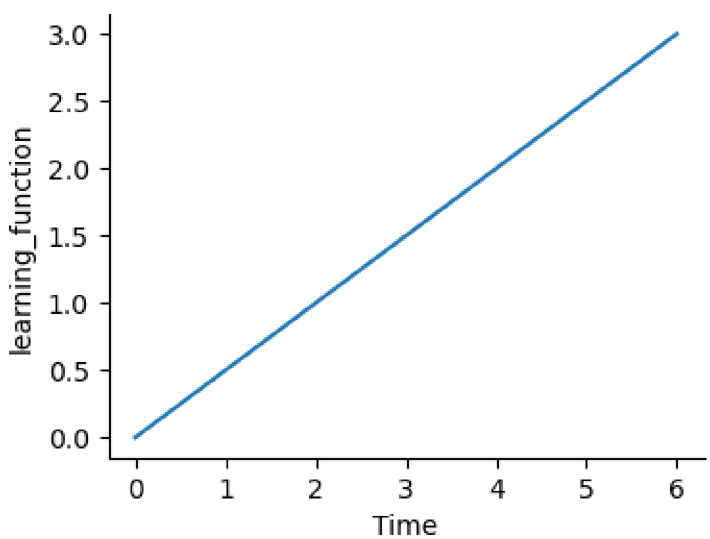
[13]:

	learning_function	cumulative_effort
0.0	0.00	0.000000
0.5	0.25	0.000000
1.0	0.50	1.875000
1.5	0.75	5.156250
2.0	1.00	8.847656
2.5	1.25	11.923828
3.0	1.50	13.846436
3.5	1.75	14.711609
4.0	2.00	14.963951
4.5	2.25	15.000000
5.0	2.50	15.000000
5.5	2.75	15.000000
6.0	3.00	15.000000

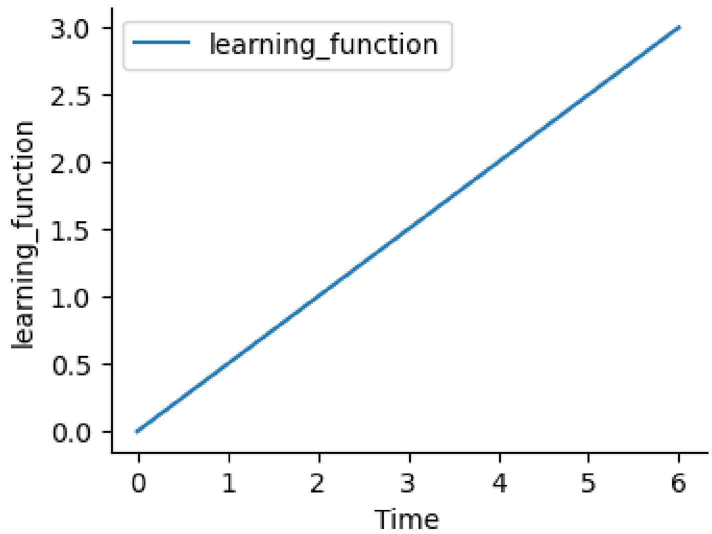
1.4 Graphs

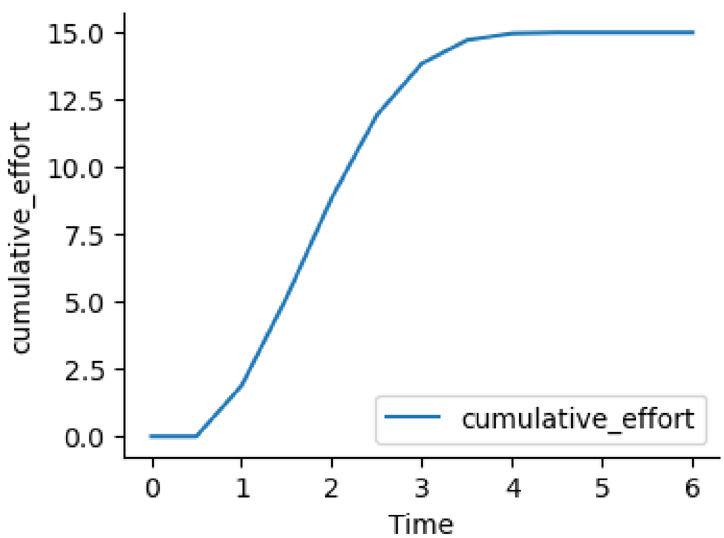
Graphs are specified in the `plot_graph` functions. It will accept a single variable to plot, or a comma separated variables printing each separately, or a list in brackets where all the variable are plotted on a single scale axis. Combinations are also accceptable.

[13]:
```
plot_graph('learning_function')
```

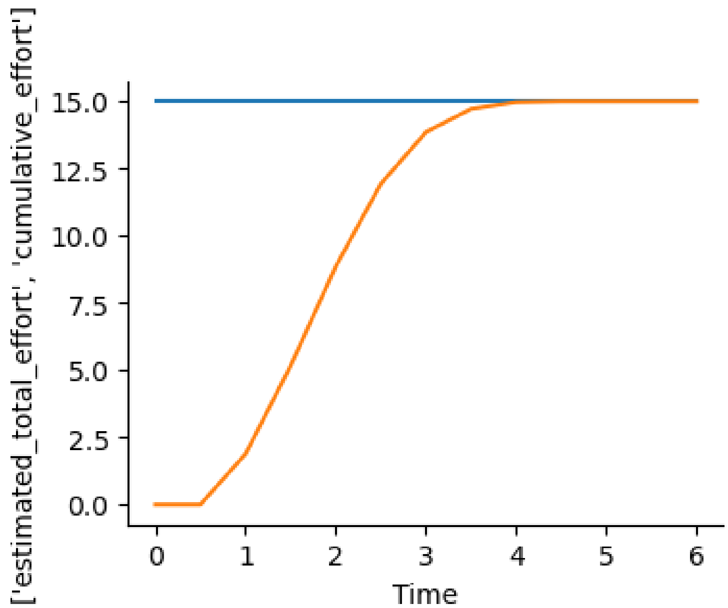


[16]:
```
plot_graph('learning_function', 'cumulative_effort')
```





[17]:
```
plot_graph(['estimated_total_effort', 'cumulative_effort'])
```



1.5 Random Number Functions

In equations for auxiliaries and rates, the random number functions supported are called as if the following import has occurred `from random import random, random.uniform`. Thus they are called with `random()` for a uniformly distributed number between 0 and 1 or `random.uniform(min, max)` for a uniformly distributed number between the min and max. For xmile format compatibility, the functions `RANDOM_0_1` and `RANDOM_UNIFORM(min, max)` are equivalent and also acceptable.

There is difference in how the random functions are treated in se-lib because they take on random values each time step. The default xmile usage draws a single random value at the beginning of each run.

[8]:
```
init_model(start=0, stop=3, dt=.5)
add_auxiliary("random_parameter", "20*random()")
run_model()
```

[8]:

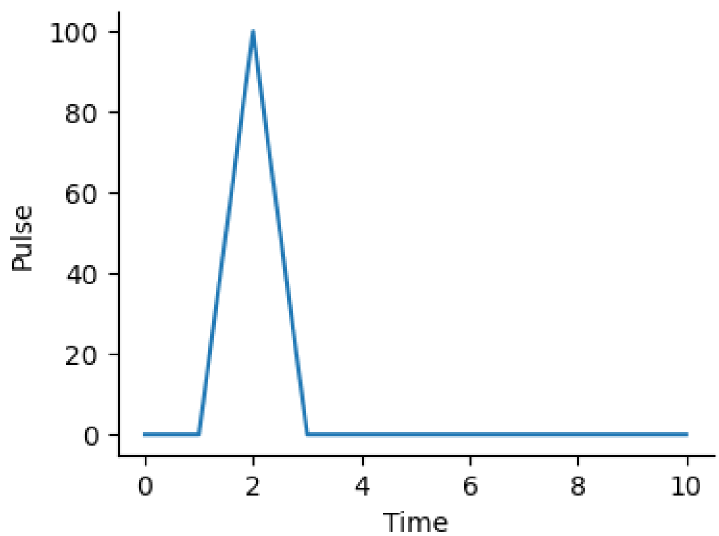
	INITIAL TIME	FINAL TIME	TIME STEP	SAVEPER	random_parameter
0.0	0	3	0.5	0.5	7.626861
0.5	0	3	0.5	0.5	17.764141
1.0	0	3	0.5	0.5	15.867612
1.5	0	3	0.5	0.5	13.049246
2.0	0	3	0.5	0.5	17.568584
2.5	0	3	0.5	0.5	0.494440
3.0	0	3	0.5	0.5	5.614978

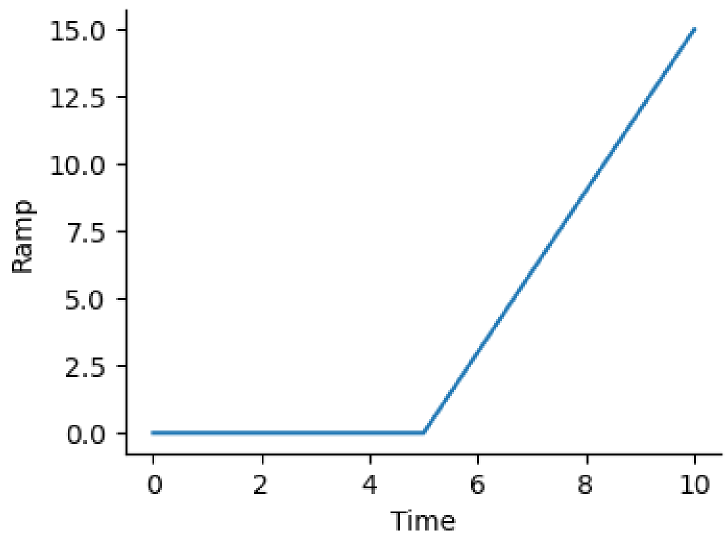
1.6 Utility Functions

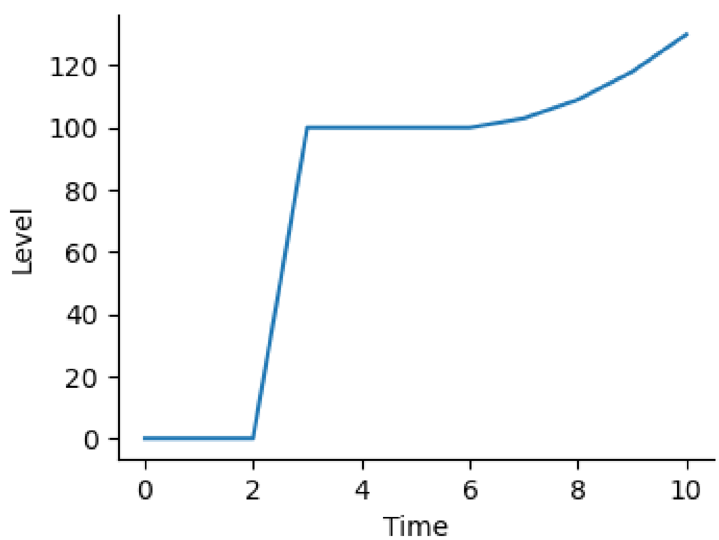
1.6.1 Test Functions

Standard test functions are available for pulse, ramp and step inputs as shown below. The full set of functions available in PySD can be used but have not all been tested.

[21]:
```
init_model(start=0, stop=10, dt=1)

add_stock("Level", 0, inflows=["Pulse", "Ramp"])
add_flow("Pulse", "pulse(100, 2)") # pulse of 100 at time 2
add_flow("Ramp", "ramp(3, 5) ") # ramp with slope 3 at time 5

run_model()
plot_graph('Pulse')
plot_graph('Ramp')
plot_graph('Level')
```







1.7 Advanced Usage

All of the features of PySD can be used in conjunction with se-lib functions. See PySD usage documentation.

1.8 Appendix A - Function Reference

See `http://se-lib.org/function_reference.html#system-dynamics`.