LoopDetect Example

This script reproduce examples given in the manual and manuscript

Resources:

[1] LoopDetect MATLAB package: https://de.mathworks.com/matlabcentral/fileexchange/81928-loopdetect/

[2] Quick tutorial: https://kabaum.gitlab.io/loopdetect_for_matlab/workflow_LoopDetect_Matlab.html

[3] Glossary of functions: https://kabaum.gitlab.io/loopdetect_for_matlab/

0. Start

0.1. Cleaning the environment

```
clear; close all; clc;
```

0.2. Installation and import

Download and unzip the content of the folder `'LoopDetect_for_Matlab'`. Within the MATLAB session, navigate to this folder and work there or add the path of the folder to MATLAB's search path for the current MATLAB session by MATLAB's `addpath()` function. Deending on where you stored the folder, its name could be something like `'/Users/Desktop/LoopDetect'` on Mac or `'C:\matlab\LoopDetect'` on Windows.

```
% Retrieve the LoopDetect folder location when having navigated to the folder
% within the MATLAB session.
LoopDetect_Folder_Name = fullfile(pwd, '..', 'LoopDetect_2025', 'src',
'loopdetect_for_matlab');
LoopDetect_Folder_Name =
char(java.io.File(LoopDetect_Folder_Name).getCanonicalPath); % normalize path
addpath(LoopDetect_Folder_Name);
```

1. First example

1.1. Loop characteristics

4 species, positive feedbacks. Firstly, we assigned 1 to all linear parameters.

```
s_star=[1,1,1,1]';
klin=ones(1,8); knonlin=[2.5,3];
loop_list=find_loops_vset(@(x)func_POSm4(1,x,klin,knonlin),s_star,10);
disp(loop_list{1})
```

```
        loop         length    sign
    _____________    ______    ____

    {[4 1 2 3 4]}      4        -1
    {[  4 2 3 4]}      3         1
    {[      1 1]}      1        -1
    {[      2 2]}      1        -1
    {[      3 3]}      1        -1
    {[      4 4]}      1        -1
```

```
first_loop=loop_list{1}.loop{1}
```

```
first_loop = 1×5
     4     1     2     3     4
```

1.2. Solving the ODE model

Now, we assigned the parameters accordingly to the manuscript, attempt to reproduce the results.

```
klin=[165,0.044,0.27,550,5000,78,4.4,5.1];
knonlin=[0.3,2];
tspan = linspace(0, 13, 13001); % Added on 2026.01.08

% Add initial value. Previously: ones(1,4)
initial_values = [1,2,3,4];
%[t,sol]=ode15s(@(t,x)func_POSm4(t,x,klin,knonlin),[0,11], initial_values); %
previous time=[0,50]
s_star=sol(end,:); %the last point of the simulation is chosen

opts = odeset('RelTol',1e-6,'AbsTol',1e-9);  % closer to typical SciPy accuracy
[t,sol] = ode15s(@(t,x) func_POSm4(t,x,klin,knonlin), tspan, initial_values, opts);
```

1.3. Calculating the Jacobian matrix

The functions `numerical_jacobian()` and `numerical_jacobian_complex()` provide numerical estimates of the Jacobian matrix of an ODE system at a chosen state vector s_*. They implement, respectively, a **finite-difference method using real perturbations** and the **complex-step method**, the latter offering higher accuracy due to the absence of subtractive cancellation errors (see Martins *et al.*, 2003) and making use of MATLAB’s built-in support for complex arithmetic.

The function handle **f** (in the example derived from `func_POSm4`, the positive-feedback chain model of Baum *et al.*, 2016) must refer to a function that returns the vector of time derivatives,

$$f_i(s) = \frac{\mathrm{dS}_i}{\mathrm{dt}}.$$

When used with `numerical_jacobian_complex()`, this function is required to depend **only** on the state variables. Any additional dependencies—such as model parameters—must be fixed beforehand so that f effectively maps only the variable vector s to its corresponding derivative vector.

```
%klin=[165,0.044,0.27,550,5000,78,4.4,5.1];
klin =[150, 0.04, 0.3, 500, 5000, 80, 4, 5];
knonlin=[0.3,2];
j_matrix=numerical_jacobian_complex(@(s)func_POSm4(1,s,klin,knonlin),...
s_star);
signed_jacobian=sign(j_matrix)
```

```
signed_jacobian = 4×4
    -1     0     0    -1
     1    -1     0     1
     0     1    -1     0
     0     0     1    -1
```

1.4. Computing all feedback loops and useful functions for loop search

```
loop_list=find_loops(j_matrix)
```

loop_list = 6×3 table

	loop	length	sign
1	[4,1,2,3,4]	4	-1
2	[4,2,3,4]	3	1
3	[1,1]	1	-1
4	[2,2]	1	-1
5	[3,3]	1	-1
6	[4,4]	1	-1

Single loops can be examined by entering the corresponding entry.

```
for i=1:3
    disp(loop_list.loop{i})
end
```

```
     4     1     2     3     4

     4     2     3     4

     1     1
```

The function `loop_summary()` provides a convenient report on total number of loops, subdivided by their lengths and signs.

```
disp(loop_summary(loop_list))
```

	length_1	length_2	length_3	length_4
total	4	0	1	1
negative	4	0	0	1
positive	0	0	1	0

One can filter the loop list for loops containing specific variables, for example the one with index 2:

```
noi = 2;
loops_with_node2=loop_list(...
    cellfun(@(z) ismember(noi,z),loop_list.loop),:)
```

loops_with_node2 = 3×3 table

	loop	length	sign
1	[4,1,2,3,4]	4	-1
2	[4,2,3,4]	3	1
3	[2,2]	1	-1

Search a loop list for loops containing specific edges defined by the indices of the ingoing and outgoing nodes. This example returns the indices of all loops with a regulation of node 3 by node 2. These are only two here.

```
loop_edge_ind=find_edge(loop_list,2,3);
loops_with_edge_2_to_3=loop_list(loop_edge_ind,:)
```

```
loops_with_edge_2_to_3 = 2×3 table
```

	loop	length	sign
1	[4,1,2,3,4]	4	-1
2	[4,2,3,4]	3	1

```
for i=1:2
    disp(loops_with_edge_2_to_3.loop{i})
end
```

```
     4     1     2     3     4

     4     2     3     4
```

Saving and reading loop lists from files can be done using MATLAB's `save()` and `load()` functions. They keep the correct data format, but objects have to be retrieved from a struct.

```
save('loop_list_example.mat', 'loops_with_node2')
loaded_loops_with_node2=load('loop_list_example.mat')
```

```
loaded_loops_with_node2 = struct with fields:
    loops_with_node2: [3×3 table]
```

```
% access the loaded data table from the struct (might not be required
% in earlier MATLAB versions)
loaded_loops_with_node2.loops_with_node2
```

```
ans = 3×3 table
```

	loop	length	sign
1	[4,1,2,3,4]	4	-1
2	[4,2,3,4]	3	1
3	[2,2]	1	-1

Reading and writing loop lists to tabular format can be performed via MATLAB's `writetable()` and `readtable()` functions. Here, we choose tabs as delimiters. Note that the formatting is lost.

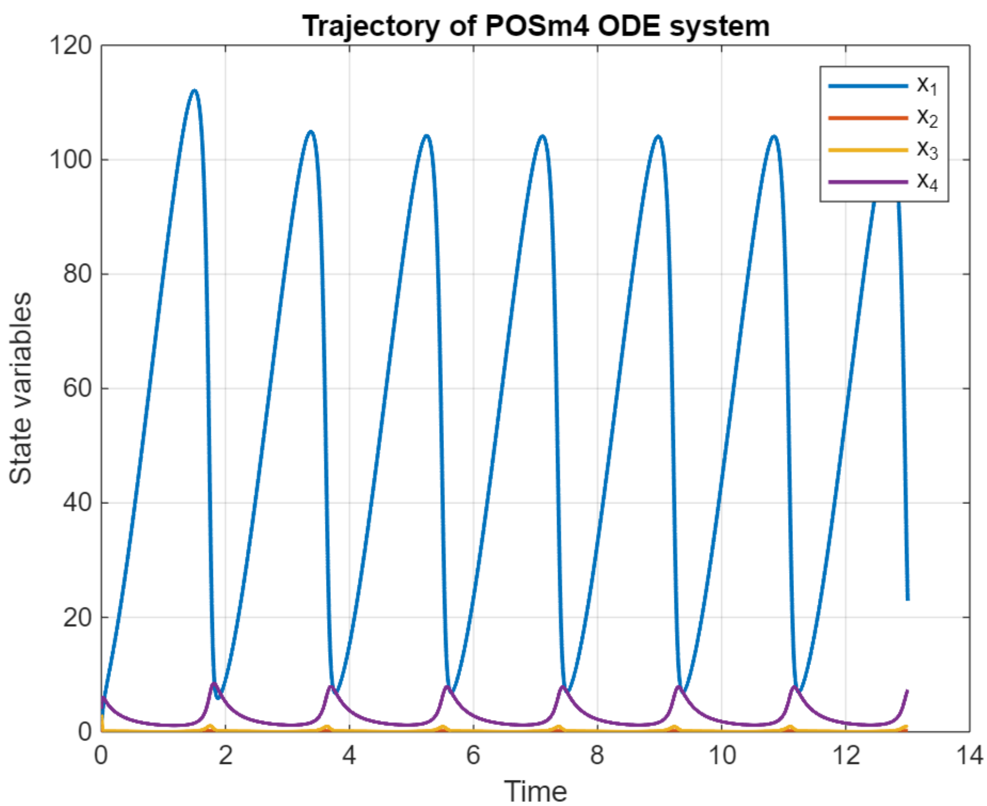
```
writetable(loops_with_node2,'loop_list_example.txt','Delimiter','\t')
loops_with_node2_readin = readtable('loop_list_example.txt')
```

```
loops_with_node2_readin = 3×7 table
```

	loop_1	loop_2	loop_3	loop_4	loop_5	length	sign
1	4	1	2	3	4	4	-1
2	4	2	3	4	NaN	3	1
3	2	2	NaN	NaN	NaN	1	-1

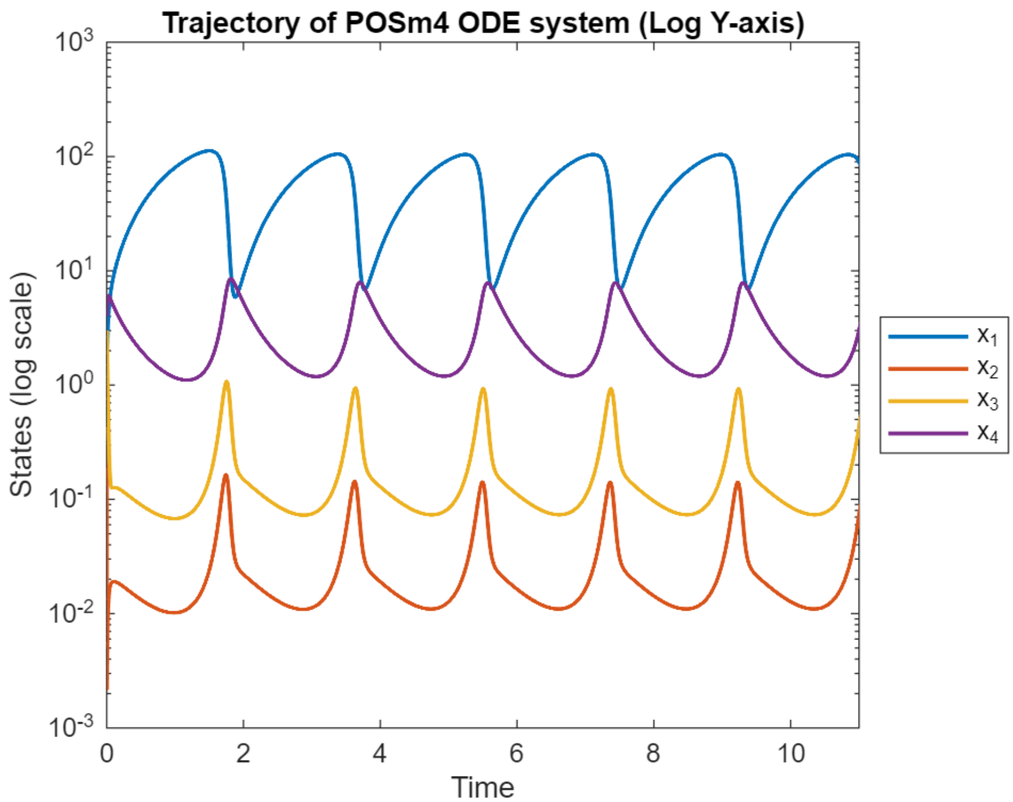
1.5. Plots

```
figure;
plot(t, sol, 'LineWidth', 1.5);
xlabel('Time');
ylabel('State variables');
title('Trajectory of POSm4 ODE system');
legend('x_1','x_2','x_3','x_4');
grid on;
```



Rescale y-axis to log-scale.

```
figure;
semilogy(t, sol, 'LineWidth', 1.5);
xlabel('Time');
ylabel('States (log scale)');
xlim([0,11]);
title('Trajectory of POSm4 ODE system (Log Y-axis)');
legend('x_1','x_2','x_3','x_4','Location','eastoutside'); % southeast
```



2. Second example

Calcium oscillation

```
function [dx] = func_gold90(t,x,klin,knonlin)
        dx=zeros(2,1);
        %J=jacob_gold90(t,x,klin,knonlin);
        dx(1)= klin(1)+klin(2)-klin(3)*x(1)^knonlin(4)/
(knonlin(1)^knonlin(4)+x(1)^knonlin(4))+klin(4)*x(2)^knonlin(5)*x(1)^knonlin(6)/
((knonlin(2)^knonlin(5)+x(2)^knonlin(5))*(knonlin(3)^knonlin(6)+x(1)^knonlin(6)))
+klin(5)*x(2)-klin(6)*x(1);
        dx(2)=klin(3)*x(1)^knonlin(4)/
(knonlin(1)^knonlin(4)+x(1)^knonlin(4))-klin(4)*x(2)^knonlin(5)*x(1)^knonlin(6)/
((knonlin(2)^knonlin(5)+x(2)^knonlin(5))*(knonlin(3)^knonlin(6)+x(1)^knonlin(6)))-
klin(5)*x(2);
    end
```

Initial values:

```
initial_conditions_calcium = [0.3920, 1.6456];
klin_calcium = [1, 7.3, 65, 500, 1, 10];
kn_calcium = [1, 2, 0.9];
n_calcium = [2, 2, 4];
```

```
knonlin_calcium = [1, 2, 0.9, 2, 2, 4]
```

```
knonlin_calcium = 1×6
    1.0000    2.0000    0.9000    2.0000    2.0000    4.0000
```

```
time_points = linspace(0, 3, 31);
```

Solve:

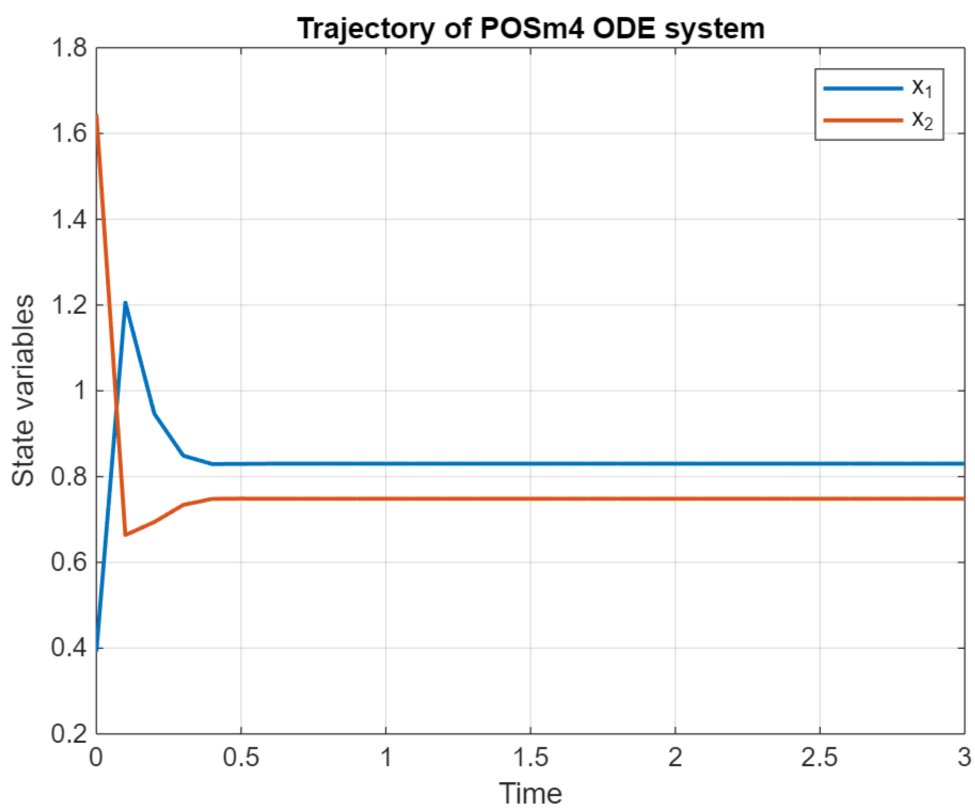
```
opts = odeset('RelTol',1e-6,'AbsTol',1e-9);  % closer to typical SciPy accuracy
[t,sol] = ode15s(@(t,x) func_gold90(t,x,klin_calcium,knonlin_calcium), time_points,
initial_conditions_calcium, opts);
s_star=sol(end,:); %the last point of the simulation is chosen
```

Visualize:

```
figure;
plot(t, sol, 'LineWidth', 1.5);
xlabel('Time');
ylabel('State variables');
title('Trajectory of POSm4 ODE system');
legend('x_1','x_2','x_3','x_4');
```

```
Warning: Ignoring extra legend entries.
```

```
grid on;
```



5. Export *.mlx to *.html

```
path = export("MATLAB/test.mlx", "MATLAB/test.pdf")
```

```
path =
'MATLAB\test.pdf'
```

```
mdfile = export("MATLAB/test.mlx","MATLAB/test.md", Format="markdown", EmbedImages=true, ...
    AcceptHTML=true)
```

```
mdfile =
'MATLAB\test.md'
```