Yet another Matlab course for control engineers

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General tips

"*Command Window*" vs "*Matlab .m scripts*" vs "*Matlab live scripts*"

Almost all code in Matlab can be written either in the Command Window (CW), in Matlab scripts (i.e., in own files with filename .m) or in Live scripts (i.e., in own files with filename .mlx). Executing the same code in different ways will lead to identical results, but there are different pros and cons in using the CW, the Matlab scripts, or the Live scripts. A summary is:

- **Command Window**: should be used only if you need to get help on some command or launch one line of code per time
- **.m scripts**: best when you want to do modular code (see the section on object oriented programming in Matlab)
- **live scripts**: best when you need to present some results to an audience

So: **do not use the Command Window for creating code.** If you want to make a small change at the beginning of the code, then in the CW you need to re-enter everything.

Getting help

Alternative 1: from the Command Window, simply enter "help xxx". E.g.,

```
% Get help on the "plot" command
help plot;
```

Alternative 2 (will return more verbose information): again from the Command Window, enter "doc xxx". E.g.,

```
% Get the documentation on the "plot" command
doc plot;
```

Alternative 3 (if you do not want to pass through the Command Window): highlight some text and press F1.

Using the Matlab workspace

All the variables you create are added to the Matlab Workspace. If a variable is stored there, then it can be used wherever you wish, whether in a .m script, a .mlx script, or as a parameter in a Simulink chart. You can double-click on the different variables to look at their values.

You can also save / load workspaces using the corresponding "save" and "load" commands.

Using the path

Matlab Command Window always refer to some path. For example, now we are working here:

```
pwd
```

```
C:\Users\damianov\MEGA\TTK4225\MatlabPreCourse\Scripts
```

If we want we can move ourselves somewhere else with the "cd" command, e.g.:

```
cd 'C:\Users\damianov\Dropbox\CSS Outreach'
```

We can also add to the system path some pre-fixed paths, e.g.:

```
addpath 'C:\Users\damianov\MEGA\Software\+MatlabToTikZ'
```

In this way we can use all the functions that are present in that folder.

Publishing your .m scripts code and results

The command "publish" lets you publish your code and results to HTML, PDF, LaTeX, among others. This is useful when you want to document the code (but don't use this for courses reports!). To use it, go to the editor, then to the "publish" tab, and then tap the arrow under the Publish icon. If you then press "Edit ..." you get a lot of choices. Here you can put various parameters including whether you want the code or not. You can also change the format.

When you publish, Matlab will run your entire .m file, bringing with it all the plots that are being made. It uses cells (%%) to create headings. Example:

```
%% Test document

% This text will appear as plain text

%% Task 1

% Here we play with figures
figure(1);
clf(1);
plot(1:10);

%% Conclusions

% We conclude that Matlab can publish documents.
```

Publishing your .mlx scripts code and results

Publishing live scripts gives the possibility of keeping the interactivity elements proper of live scripts. The workflow is similar to publishing .m scripts. See https://se.mathworks.com/help/matlab/matlab_prog/publishing-matlab-code.html for more information.

Basic stuff

Control Flow Statements

For loops

```
% creates the vector and starts the loop
for iCounter = 1:10
    %
    % do something
    %
end % ends the loop
```

Remarks:

- no parentheses (as in C / C ++) to end the block

If-then-else

```
if iCounter == 20
    % do something
elseif iCounter >= 21
    % do something else
else%
    % do yet something else
end %
```

Remarks:

- "`if iCounter == 20`", NOT "`if iCounter = 20`"! Otherwise you are doing an assignment...

While

```
while iCounter == 2020
    % do something
end %
```

Switch

```
cUserChoice = '' % insert a character here
```

```
cUserChoice =

  0×0 empty char array
```

```
switch cUserChoice
   case 'a'
       % do something
   case 'b'
       % do something else
   otherwise
       % do yet something else
end %
```

Remarks:

- 'switch' is VERY USEFUL in conjunction with varargin and nargin (i.e., when wanting to have a flexible number of function input arguments)

Vectors

Create vectors using the colon operator ":"

Use a syntax like "vector = first : spacing : last". E.g.:

```
% create a vector from 1 to 10
afVectorA = 1:10

% create a vector containing 1 3 5 7 9
afVectorB = 1:2:10

% create a vector containing -1 -3 -5 -7 -9
afVectorC = -1:-2:-10
```

Create vectors using the linspace and logspace methods

```
% create 30 samples linearly spaced between 1 and 100 (included
afVectorD = linspace( 1, 100, 30 )
```

```
afVectorD = 1×30
    1.0000    4.4138    7.8276   11.2414   14.6552   18.0690   21.4828   24.8966 ···
```

```
% create 7 samples logarithmically spaced between 10^(-2) and 10^(+4)
afVectorE = logspace( -2, 4, 7 )
```

```
afVectorE = 1×7
10^4 ×
    0.0000    0.0000    0.0001    0.0010    0.0100    0.1000    1.0000
```

Create vectors using square brackets

Both with and without commas work the same (but be careful to be consistent!)

```
afVectorD = [ 1, 5,   9,  13];
afVectorE = [-1  0.5  80  4];
```

Extract values from a vector

```
afVectorA(1)     % extracts the first element
```

```
ans = 1
```

```
afVectorB(3)     % extracts the third element
```

```
ans = 5
```

```
afVectorC(2:3)   % extracts the second and third element
```

```
ans = 1×2
    -3    -5
```

```
afVectorD([1,3]) % extracts the first, second and third element
```

```
ans = 1×2
     1     9
```

```
afVectorE(2:end) % extracts from the second to the last element
```

```
ans = 1×3
    0.5000   80.0000    4.0000
```

Matrices

Create matrices using square brackets

```
aafMatrixA = [ 1  2  3;
               4  5  6;
               7  8  9 ]
```

```
aafMatrixA = 3×3
     1     2     4
     5    -1     2
     9     9     0
```

Extract values from a matrix

Again, use the colon operator ":". For example:

```
aafMatrixA( 1:2, 2:3 )  % extracts the submatrix formed by the first two rows
```

```
ans = 2×2
     2     4
    -1     2
```

```
                        % and the last two colums

aafMatrixA( :, 2:3 )    % extracts the submatrix formed by all the rows
```

```
ans = 3×2
     2     4
    -1     2
     9     0
```

```
                        % and the last two colums
```

Create multi-dimensional matrices

```
aaafMatrix = zeros( 3, 2, 4 );

for iCounterA = 1:size( aaafMatrix, 1 )
for iCounterB = 1:size( aaafMatrix, 2 )
for iCounterC = 1:size( aaafMatrix, 3 )
    %
    aaafMatrix( iCounterA, iCounterB, iCounterC ) = ...
```

```
        iCounterA * iCounterB - iCounterC;
    %
end %
end %
end %
```

Extract values from a multi-dimensional matrix

```
aaafMatrix( :, 2, : )          % get the 'second' slice
```

```
ans =
ans(:,:,1) =

     1
     3
     5


ans(:,:,2) =

     0
     2
     4


ans(:,:,3) =

    -1
     1
     3


ans(:,:,4) =

    -2
     0
     2
```

```
squeeze(aaafMatrix( :, 2, : )) % get the slice in a more convenient format
```

```
ans = 3×4
     1     0    -1    -2
     3     2     1     0
     5     4     3     2
```

Using ";" to prevent display messages in the command window

```
afVectorA(1)     % shows the results in the command window
afVectorB(3);    % does not show the results in the command window
```

More advanced stuff

Making plots that don't make others cringe

If you want to do plots in Matlab, see the suggestions in http://folk.ntnu.no/damianov/Matlab/HowToMakePrettyFiguresWithMatlab.pdf and the templates in http://folk.ntnu.no/damianov/matlab.html.

If you want to do plots in LaTeX/TikZ, see the suggestions, templates and video-instructions in http://folk.ntnu.no/damianov/LaTeX.html.

Learn how to do plots in LaTeX/TikZ asap.

Importing data

- you have just a table of numbers? Then use `load()`
- you have a table of numbers with nonnumeric column and/or row headers? Then use importdata()
- you have a table of numeric/nonnumeric things, e.g., columns of characters or formatted dates or times? Then use `textscan()`
- you don't even have a table, i.e., each row has got its own number of columns? Then use `fgetl()`

Want more details? See the documentation and https://se.mathworks.com/learn/tutorials/matlab-onramp.html, lesson 11.

Taking good coding habits

In general, see http://folk.ntnu.no/damianov/Matlab/CodingRules.pdf

Important messages:

- people will judge you based on how you indent the code;
- program as a stereotypical granny drive;
- premature optimization is the root of ***most*** evil.

Use at least modular, at best object oriented programming paradigms

- **be modular**: if a piece of code does a specific logical operation, make it become a function
- **be object-oriented**: structure the logic of your program into objects that interact with one another, that have their own properties, and that have own methods to manage the interactions among the objects.

Pros for object-oriented: faster debugging, better maintainability, better portability, **you don't seem a fool** when you start working for serious teams / companies

Cons for object-oriented: need some little more time at the beginning of each project. As soon as the final code will be more than 300 lines of code probably better to do OOP.

For templates on how to create and manage classes in Matlab, see http://folk.ntnu.no/damianov/Matlab/@TemplateClass/.

Use nargin and varargin to increase modularity

Example:

```
function ExportLineplot(     ...
strFileName,       ...
aafSignals,       ...
```

```
        astrHeader       ) % optional

        % flag if there exists the header
        bHeaderIsPresent = ( nargin > 2 );

        % if the header is not there, then create it
        if( bHeaderIsPresent )
        astrHeader = % something
        end;

        % ... some other code ...

        end % function
```

Use errors and warnings to find and prevent bugs

Always place warnings to follow up whether a user-choice has been made consistently with the available choices. Example (would have been more meaningful within a function, though):

```
% initialization
bUserChoiceIsWellFormed = false;

while( ~bUserChoiceIsWellFormed )
    %
    % tell the user her/his options
    fprintf( 'a = option 1, b = option 2' )
    %
    % get the user input
    cUserChoice = 'c';
    %
    % check
    if(     cUserChoice ~= 'a'  ...
        &&  cUserChoice ~= 'b'  )
        %
        warning('badly formed user choice!')
        %
    end % if
    %
end % while
```

```
a = option 1, b = option 2a = option 1, b = option 2a = option 1, b = option 2a = option 1, b = option 2a = option 1
```

Place errors to check if the code is in places where it should never enter. Example:

```
fMyPositiveParameter = -1;  % something strange happened before and created
                            % a situation that we should never encounter

if( fMyPositiveParameter < 0 )
    %
    error('something strange happened; Did a bug occur in method XXX?')
    %
end %
```

Adopt tricks to improve both the speed and the style

Check http://www-users.math.umn.edu/~lerman/math5467/matlab_adv.pdf, chapter 6.

Solving numerical optimization problems

I.e., finding the parameters that maximize or minimize a function that you can evaluate from quantitative perspectives.

Typical scenario: `goodness_of_my_simulation = function( a_lot_of_parameters )`. Then:

- may your parameters be whatever you want? Then use `fminunc()`
- do you have some constraints on your parameters? Then use `fmincon()`

Example:

```
% definition of the Rosenbrock's cost through an anonymous function
CostFunction = @(x) 100 * ( x(2) - x(1)^2 )^2 + ( 1 - x(1) )^2;

% definition of a constraint of the type A x >= b
A = [ 1, 2 ];
b = 1;

% definition of where we start the search
x0 = [ -1, 2 ];

% compute the optimal x
x = fmincon( CostFunction, x0, A, b )
```

```
Local minimum found that satisfies the constraints.

Optimization completed because the objective function is non-decreasing in
feasible directions, to within the value of the optimality tolerance,
and constraints are satisfied to within the value of the constraint tolerance.

<stopping criteria details>
x = 1×2
    0.5022    0.2489
```

PS: https://se.mathworks.com/help/matlab/matlab_prog/anonymous-functions.html. Anonymous functions help not having to edit and maintain files for functions that require only a **local** definition.

Using symbolic variables

Differentiation with symbolic variables

TODO

Differentiation without symbolic variables

TODO

Integration with symbolic variables

TODO

Partial derivatives

TODO

Ordinary differential equations

Disclaimer: this is a big topic!! See https://se.mathworks.com/help/matlab/ordinary-differential-equations.html for a more comprehensive treatment.

We here make a simple example: the Lotka-Volterra system, i.e.,

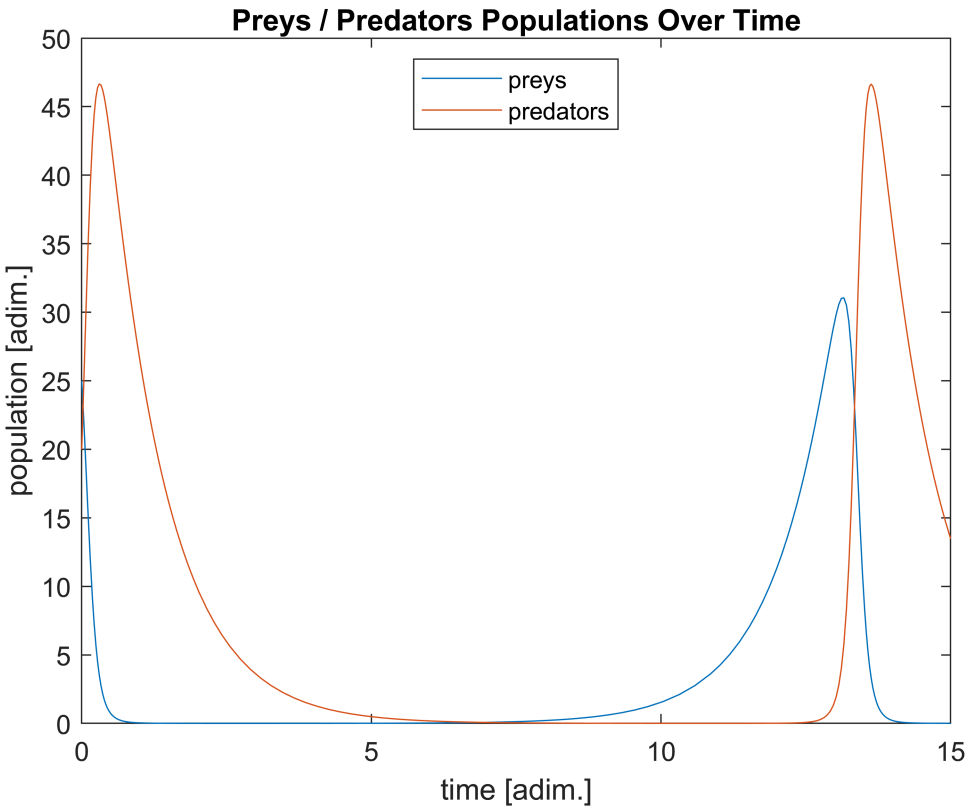
$$\begin{cases} \dot{y}_1 &= y_1 - \alpha y_1 y_2 \\ \dot{y}_2 &= -y_2 + \beta y_1 y_2 \end{cases}$$

The first thing is to define an opportune function capturing the dynamics of the system, i.e.,

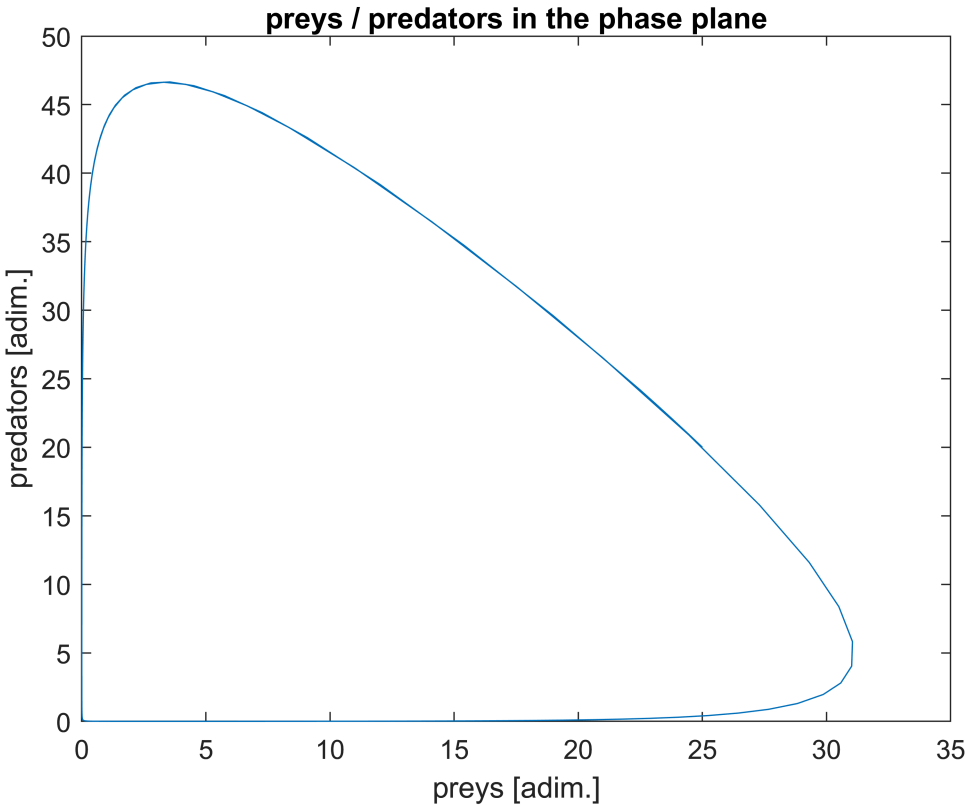
```
function dy = dydt(t, y, a, b)

dy = [   y(1) - a * y(1) * y(2)  ; ...
- y(2) + b * y(1) * y(2)  ];

end % function
```

Note that the functions like the above one should always have the two initial parameters as `t` and `y`, and always return column vectors. Then the code to solve the ODE can be something as follows:

```
% define the parameters of the model
a = 0.2;
b = 0.3;

% define the time interval for the analysis
tstart = 0;
tend   = 15;

% define the initial condition
y0 = [25; 20];

% solve the ODE
[t, y] = ode45(@(t, y) dydt(t, y, a, b), [tstart tend], y0);

% plot the time signals
plot(t,y)
title('Preys / Predators Populations Over Time')
xlabel('time [adim.]')
ylabel('population [adim.]')
legend('preys', 'predators', 'Location', 'North')
```




```
% plot the phase plane
plot(y(:,1), y(:,2))
title('preys / predators in the phase plane')
xlabel('preys [adim.]')
ylabel('predators [adim.]')
```



Interesting stuff for control engineers

Modelling

Analysis

PIDs

Root locus

Transfer functions

State space systems

Digital control

http://ctms.engin.umich.edu/CTMS/

References

Free courses, for generic audiences

1. http://www-users.math.umn.edu/~lerman/math5467/matlab_adv.pdf
2. https://se.mathworks.com/learn/tutorials/matlab-onramp.html

Free courses, but designed specifically for control engineers

1. http://ctms.engin.umich.edu/CTMS/

For profit courses

1. https://www.udemy.com/course/matlab-programming-fundamentals

Pedagogical material for instructors

1. Kirschner, Sweller, Clark. "Why Minimal Guidance During Instruction Does Not Work: An Analysis of the Failure of Constructivist, Discovery, Problem-Based, Experiential, and Inquiry-Based Teaching", Educational Psychologist, 41(2), 75-86, 2006