A0B17MTB – Matlab

Part #4

Miloslav Čapek
miloslav.capek@fel.cvut.cz

Filip Kozák, Viktor Adler, Pavel Valtr

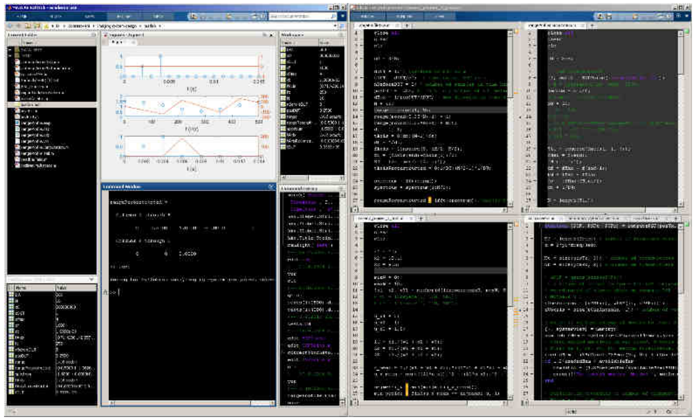
Department of Electromagnetic Field
B2-626, Prague

Learning how to …

Matlab Editor

Relational and logical operators

Data type `cell`



Matlab Editor

- it is often wanted to evaluate certain sequence of commands repeatedly $\Rightarrow$ utilization of Matlab scripts (plain ACSII coding)
- the best option is to use `Matlab Editor`
  - to be opened using:

```
>> edit
```

  - or in Matlab < R2012a: `Start` $\rightarrow$ `Desktop Tools` $\rightarrow$ `Editor`
- a script is a sequence of statements that we have been up to now typing in the command line
  - all the statements are executed one by one on the launch of the script
  - the script operates with global data in `Matlab Workspace`
  - suitable for quick analysis and solving problems involving multiple statements
- there are specific naming conventions for scripts (and also for functions as we see later)

Script execution, m-files

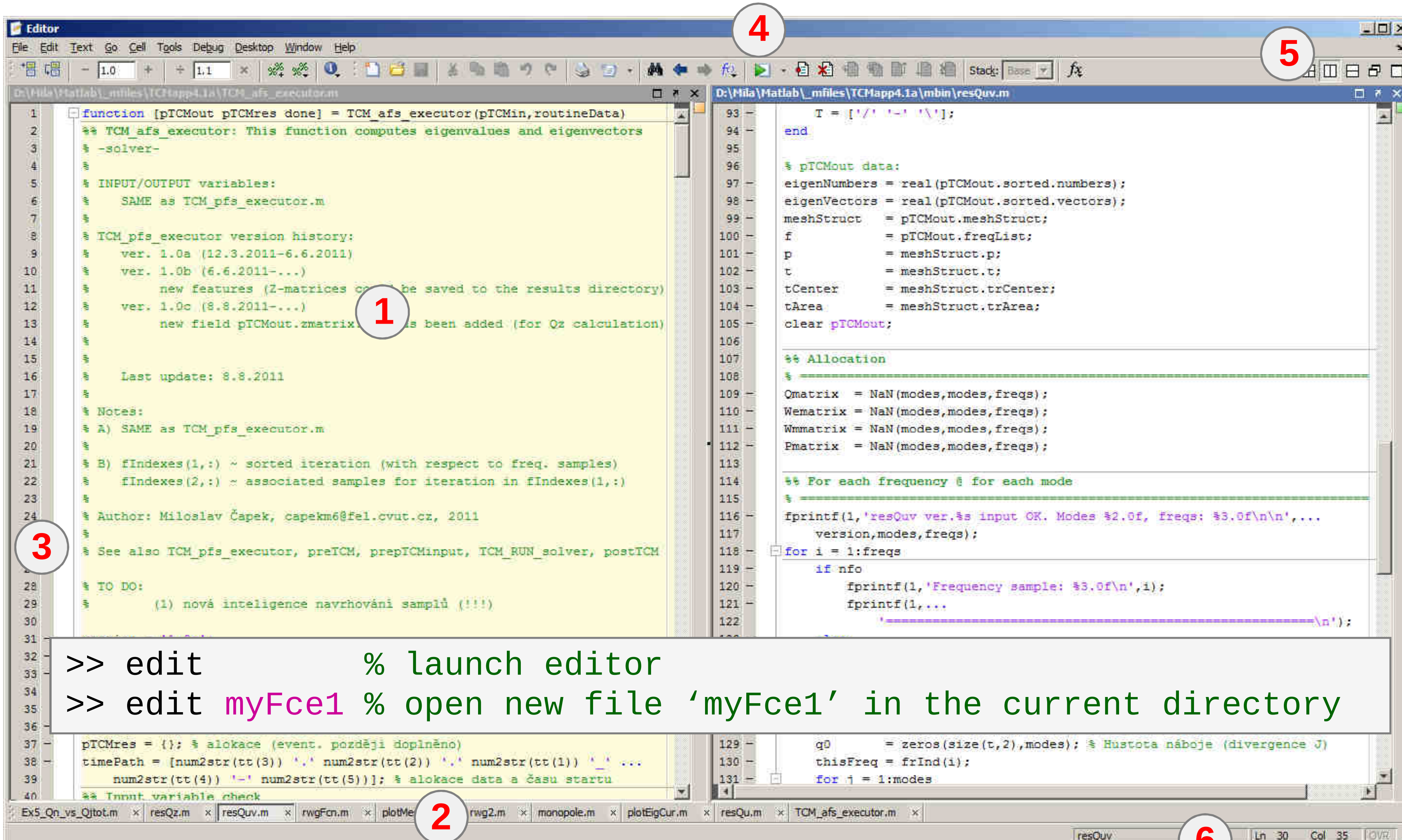
- to execute script:
  - F5 function key in Matlab Editor
  - Current Folder → select script → context menu → Run
  - Current Folder → select script → F9
  - From the command line:

```
>> script_name
```

- Scripts are stored as so called m-files
  - `.m`
  - caution: if you have Mathematica installed, the .m files may be launched by Mathematica

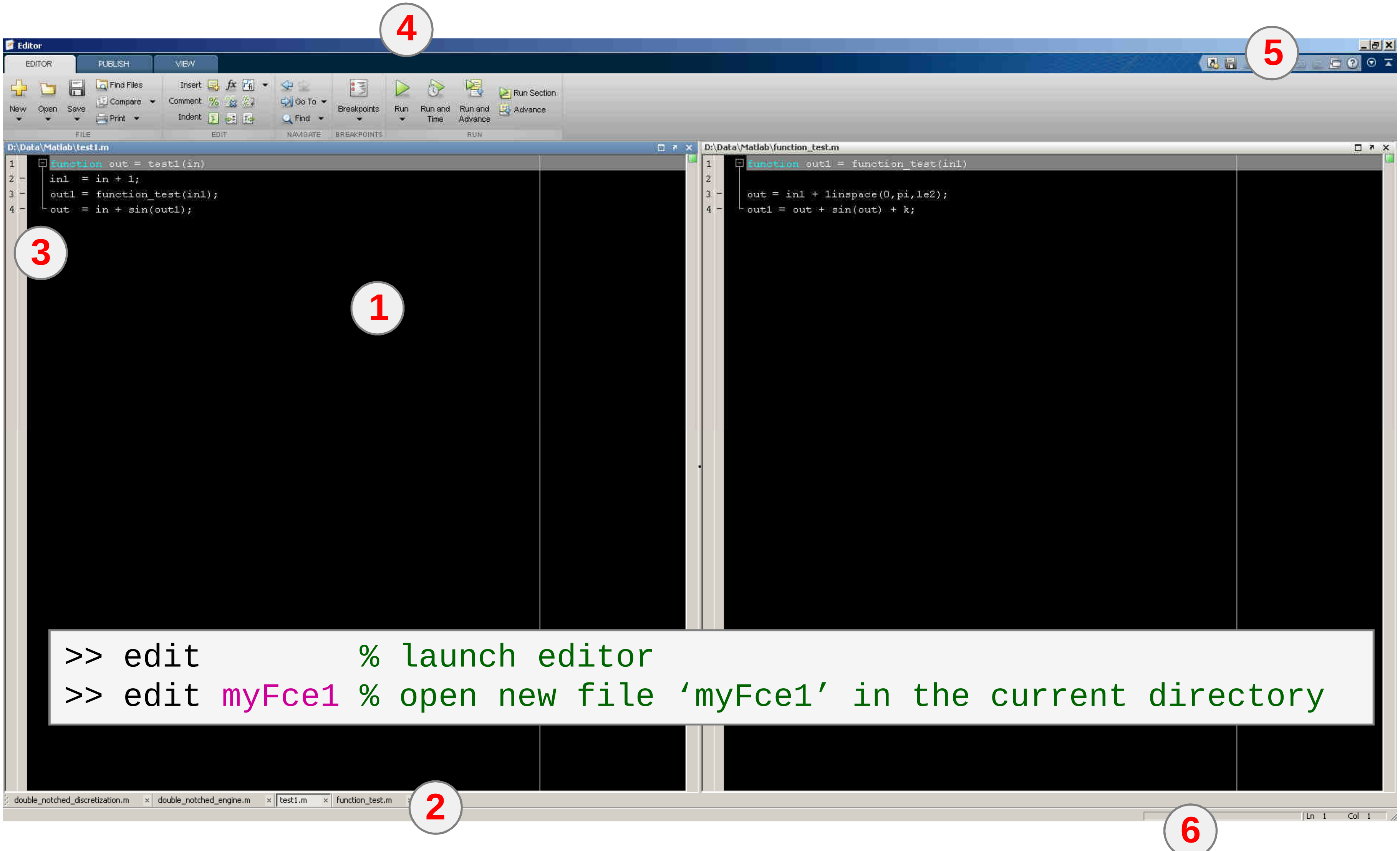
Department of Electromagnetic Field, CTU FEE, miloslav.capek@fel.cvut.cz

Matlab Editor, < R2012a




```
>> edit          % launch editor
>> edit myFce1 % open new file 'myFce1' in the current directory
```

Matlab Editor, ≥ R2012a




```
>> edit          % launch editor
>> edit myFce1 % open new file ‘myFce1’ in the current directory
```

Useful shortcuts for Matlab Editor

key	meaning
`CTRL + Pg. UP`	switch among all open m-files - one direction
`CTRL + Pg. DOWN`	- other direction
`CTRL + R`	adds ‘%’ at the beginning of the selected lines, “comment lines“
`CTRL + T`	removes ‘%’ from selected lines
`F5`	execute current script / function
`CTRL + S`	save current file (done automatically after pressing F5)
`CTRL + HOME`	jump to the beginning of file
`CTRL + END`	jump to the end of file
`CTRL + → / ←`	jump word-by-word or expression-by-expression to the right / left
`CTRL + W`	close current file
`CTRL + O`	activates open file dialog box (drag and drop technique also available)
`CTRL + F`	find / replace dialog box
`CTRL + G`	„go to“, jumps to the indicated line number
`CTRL + D`	open m-file of the function at the cursor's position
`CTRL + I`	indention of block of lines corresponding to key words (`for` / `while`, `if` / `switch` – `case`)
`F1`	open context help related to the function at position of cursor

Matlab Editor

120 s

- open `Matlab Editor` and prepare to work with a new script, call it `signal1.m`, for instance
- use signal generation and limiting from one of the previous slides as the body of the script
- Save the script in the current (or your own) folder
- try to execute the script (F5)

```
>> edit signal1
```

```
%% script generates signal with noise
clear; clc;
t = linspace(0, 5, 5*40);
s_t = sqrt(2*pi)*sin(2*pi*t) + randn(1, 5*40);
plot(t, s_t);
```

- note: from now on, the code inside scripts will be shown without leading „>>“

Useful functions for script generation

- function `disp` displays value of a variable in `Command Window`
  - without displaying variable's name and the equation sign "="
  - Can be combined with s text (more on that later)
  - more often it is advantageous to use more complicated but robust function `sprintf`

```
>> a = 2^13-1;
b = [8*a 16*a];
b

b =

       65528      131056
```

```
a = 2^13-1;
b = [8*a 16*a];
b
```

vs.

```
a = 2^13-1;
b = [8*a 16*a];
disp(b);
```

```
>> a = 2^13-1;
b = [8*a 16*a];
disp(b);
       65528      131056
```

- function `input` is used to enter variables
  - if the function is terminated with an error, the input request is repeated

```
A = input('Enter parameter A: ');
```

  - It is possible to enter strings as well:

```
str = input('Enter String str: ', 's');
```

```
>> A = input('Enter parametr A: ');
Enter parametr A: 10.153
>> A = input('Enter string str: ', 's');
Enter string str: this is a test
>> whos
  Name      Size            Bytes  Class     Attributes

  A         1x14               28  char
  ans       1x1                 8  double
```


Department of Electromagnetic Field, CTU FEE, miloslav.capek@fel.cvut.cz

Matlab Editor – Exercise

600 s

- create a script to calculate compound interest*
  - the problem can be described as :

$$P = \frac{rA\left(1+\frac{r}{n}\right)^{nk}}{n\left(\left(1+\frac{r}{n}\right)^{nk}-1\right)},$$

where P is regular repayment of debt A, paid n-times per year in the course of k years with interest rate r (decimal number)

  - create a new script and save it
  - at the beginning delete variables and clear `Command Window`
  - implement the formula first, then proceed with inputs (`input`) and outputs (`disp`)
  - Try to vectorize the code, e.g. for various values of P, n or k
  - Check your results (for A = 1000, n = 12, k = 15, r = 0.1 is P = 10.7461)

*interest from the prior period is added to principal

Department of Electromagnetic Field, CTU FEE, miloslav.capek@fel.cvut.cz

Matlab Editor – Exercise

- try to vectorize the code, both for r and k

$$P = \frac{rA\left(1+\frac{r}{n}\right)^{nk}}{n\left(\left(1+\frac{r}{n}\right)^{nk}-1\right)}$$

- use scripts for future work with Matlab
  - bear in mind, however, that parts of the code can be debugged using command line

Useful functions for script generation

- function `keyboard` stops execution of the code and gives control to the keyboard
  - the function is widely used for code debugging as it stops code execution at the point where doubts about the code functionality exist

```
K>>
```

  - `keyboard` status is indicated by `K>>` (K appears before the prompt)
  - The keyboard mode is terminated by `dbcont` or press F5 (Continue)
- function `pause` halts code execution,
  - `pause(x)` halts code execution for `x` seconds

```
% code; code; code;
pause;
```

- see also: `echo`, `waitforbuttonpress`
  - special purpose functions

Department of Electromagnetic Field, CTU FEE, miloslav.capek@fel.cvut.cz

Matlab Editor – Exercise

360 s ↑

- modify the script for compound interest calculation in the way that
  - values *A* and *n* are entered from the command line (function `input`)
  - test the function `keyboard` (insert it right after parameter input)
    - is it possible to use `keyboard` mode to change the parameters inserted by `input`?
    - arrange for exiting the `keyboard` (`K>>`) mode, use `dbcont`
  - interrupt the script before displaying results (function `pause`)
    - note the warning „*Paused*“ in the bottom left part of main Matlab window

Script commenting

- **MAKE COMMENTS!!**
  - important / complicated parts of code
  - description of functionality, ideas, change of implementation

typical comment
(one-/multiple- line)

enables to separate
function into more
blocs
(%% …)

Multiple-line
comment

```
% A    = magic(3);
matX = dataIn(:,1);
SumX = sum(matX); % all members are summed
%% CELL mode (must be enabled in Editor)
disp(num2str(SumX));
Z = inv(ZZ);
%{
This is a multi-line comment.
Mostly, it is more appropriate to use more
single-line comments.
%}
```

Shortcuts:
CTRL+R
CTRL+T

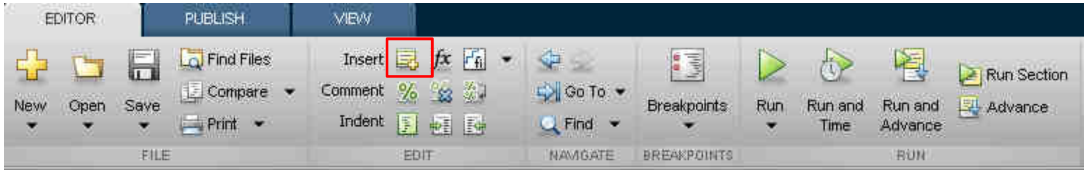
Department of Electromagnetic Field, CTU FEE, miloslav.capek@fel.cvut.cz

When not making comments…

- …
  no
  one
  will
  understand!

```
edgTotal  = MeshStruct.edgTotal;
RHO_P     = zeros(3,9,edgTotal);
RHO_M     = zeros(3,9,edgTotal);
for m = 1:edgTotal
    RHO_P(:,:,m) = repmat(MeshStruct.Rho_Plus1(:,m),[1 9]);
    RHO_M(:,:,m) = repmat(MeshStruct.Rho_Minus1(:,m),[1 9]);
end
Z         = zeros(edgTotal,edgTotal) + 1j*zeros(edgTotal,edgTotal);
for p = 1:MeshStruct.trTotal
    Plus  = find(MeshStruct.TrianglePlus - p == 0);
    Minus = find(MeshStruct.TriangleMinus - p == 0);
    D     = MeshStruct.trCenter9 - ...
                repmat(MeshStruct.trCenter(:,p),[1 9 MeshStruct.trTotal]);
    R     = sqrt(sum(D.*D));
    g     = exp(-K*R)./R;
    gP    = g(:,:,MeshStruct.TrianglePlus);
    gM    = g(:,:,MeshStruct.TriangleMinus);
    Fi    = sum(gP) - sum(gM);
    ZF    = FactorFi.*reshape(Fi,edgTotal,1);
    for k = 1:length(Plus)
        n      = Plus(k);
        RP     = repmat(MeshStruct.Rho_Plus9(:,:,n),[1 1 edgTotal]);
        RPi    = repmat(MeshStruct.Rho_Minus9(:,:,n),[1 1 edgTotal]);
        A      = sum(gP.*sum(RP.*RHO_P)) + sum(gM.*sum(RP.*RHO_M));
        Z1     = FactorA.*reshape(A,edgTotal,1);
        Z(:,n) = Z(:,n) + MeshStruct.edgLength(n)*(Z1+ZF);
    end
    for k = 1:length(Minus)
        n      = Minus(k);
        RP     = repmat(MeshStruct.Rho_Minus9(:,:,n),[1 1 edgTotal]);
        RPi    = repmat(MeshStruct.Rho_Plus9(:,:,n),[1 1 edgTotal]);
        A      = sum(gP.*sum(RP.*RHO_P)) + sum(gM.*sum(RP.*RHO_M));
        Z1     = FactorA.*reshape(A,edgTotal,1);
        Z(:,n) = Z(:,n) + MeshStruct.edgLength(n)*(Z1-ZF);
    end
end
```

Cell mode in Matlab Editor



- cells enable to separate the code into smaller logically compact parts
  - separator: **%%**
  - the separation is visual only, but it is possible to execute a single cell - shortcut CTRL+ENTER
- in the older versions of Matlab, it is usually necessary to activate the cell mode

Cell mode in Matlab Editor

240 s

- split previous script (`loanRepayment.m`) into separate parts
  - use the (cell) separator **%%**

Department of Electromagnetic Field, CTU FEE, miloslav.capek@fel.cvut.cz

Data in scripts

- scripts can use data that has appeared in Workspace
- variables remain in the Workspace even after the calculation is finished
- operations on data in scripts are performed in the base Workspace

Department of Electromagnetic Field, CTU FEE, miloslav.capek@fel.cvut.cz

Naming conventions of scripts and functions

- names of scripts and functions
  - max. number of characters is 63 (additional characters are ignored)
  - naming restrictions similar to variable names apply
  - choose names describing what the particular function calculates
  - avoid existing names as the new script is called instead of an existing built-in function (overloading can occur)
- more information:
  - `http://www.mathworks.com/matlabcentral/fileexchange/2529-matlab-programming-style-guidelines`

- in the case you want to apply vector functions row-wise
  - check whether the function enables calculation in the other dimension (`max`)
  - transpose your matrix
  - some of the functions work both column-wise and row-wise (`sort` × `sortrows`)

Department of Electromagnetic Field, CTU FEE, miloslav.capek@fel.cvut.cz

startup.m script

- script `startup.m`
  - always executed at Matlab start-up
  - it is possible to put your predefined constants and other operations to be executed (loaded) at Matlab start-up

- location (use `>> which startup`):
  - `...\Matlab\R201Xx\toolbox\local\startup.m`

- change of base folder after Matlab start-up :

```
%% script startup.m in ..\Matlab\Rxxx\toolbox\local\
clc;
disp('Workspace is changing to:');
cd('d:\Data\Matlab\');
cd
disp(datestr(now, 'mmmm dd, yyyy HH:MM:SS.FFF AM'));
```

```
Workspace is changing to:

d:\Data\Matlab

February 25, 2014  3:36:03.347 PM
Keep on working...
>>
```

`matlabrc.m` script

- executed at Matlab start-up (or manually executed: `>> matlabrc`)
- contains some basic definitions, e.g.
  - figure size, set-up of some graphic elements
  - sets Matlab path (see later)
  - and others
- in the case of a multi-license it is possible to insert a message in the script that will be displayed to all users at the start-up
- location (use `>> which matlabrc`):
  - `...\Matlab\R201Xx\toolbox\local\matlabrc.m`

- last of all, `startup.m` is called (if existing)

- `matlabrc.m` is to be modified only in the case of absolute urgency!

Department of Electromagnetic Field, CTU FEE, miloslav.capek@fel.cvut.cz

Relational operators

- to inquire, to compare, <u>whether ‘something’ is greater than, lesser than, equal to etc.</u>
- the result of the comparison is always either
  - positive (`true`), logical one „1“
  - negative (`false`), logical zero „0“

>	greater than
>=	greater than or equal to
<	lesser than
<=	lesser than or equal to
==	equal to
~=	not equal to

- all relational operators are vector-wise
  - it is possible to compare as well vectors vs. vectors, matrices vs. matrices, …
- often in combination with logical operators (see later)
  - more relational operators applied to a combination of expressions

Relational operators

300 s

- having the vector $\mathbf{G} = \begin{pmatrix} \frac{\pi}{2} & \pi & \frac{3}{2}\pi & 2\pi \end{pmatrix}$, find elements of $\mathbf{G}$ that are
  - greater than π
  - lesser or equal to π
  - not equal to π

- try similar operations for $\mathbf{H} = \mathbf{G}^{\mathrm{T}}$ as well

- try to use relational operators in the case of a matrix and scalar as well

- find out whether $\mathbf{V} \geq \mathbf{U}$:

$$\mathbf{V} = \begin{pmatrix} -\pi & \pi & 1 & 0 \end{pmatrix}$$

$$\mathbf{U} = \begin{pmatrix} 1 & 1 & 1 & 1 \end{pmatrix}$$

Relational operators

200 s

- find out results of following relations
  - try to interpret the results

```
>> 2 > 1 & 0 % ???
```

```
>> r = 1/2;
>> 0 < r < 1 % ???
```

```
>> (1 > A) <= true
```


Department of Electromagnetic Field, CTU FEE, miloslav.capek@fel.cvut.cz

Logical operators

- to enquire, to find out, whether particular condition is fulfilled
- the result is always either
  - positive (`true`), logical one „1“
  - negative (`false`), logical zero „0“

`&`	`and`
`|`	`or`
`~`	`not`
	`xor`
	`all`
	`any`

- `all`, `any` is used to convert logical array into a scalar
- Matlab interprets any numerical value except `0` as `true`
- all logical operators are vector-wise
  - it is possible to compare as well vectors vs. vectors, matrices vs. matrices, …
- functions `is*` extend possibilities of logical enquiring
  - we see later

Logical operators – application

- assume a vector of 10 random numbers ranging from -10 to 10

```
>> a = 20*rand(10, 1) - 10
```

  - following command returns `true` for elements fulfilling the condition:

```
>> a < -5 % relation operator
```

  - following command returns values of those elements fulfilling the condition (logical indexing):

```
>> a(a < -5)
```

  - following command puts value of -5 to the position of elements fulfilling the condition :

```
>> a(a < -5) = -5
```

  - following command sets value of the elements in the range from -5 to 5 equal to zero (opposite to tresholding):

```
>> a(a > -5 & a < 5) = 0
```

  - tresholding function (values below -5 sets equal to -5, values above 5 sets equal to 5):

```
>> a(a < -5 | a > 5) = sign(a(a < -5 | a > 5))*5
```

Logical operators

420 s

- determine which of the elements of the vector $\mathbf{A} = \begin{pmatrix} \frac{\pi}{2} & \pi & \frac{3}{2}\pi & 2\pi \end{pmatrix}$

  - are equal to π <u>or</u> are equal to 2π
    - pay attention to the type of the result (= logical values `true` / `false`)

  - are greater than π/2 <u>and at the same time</u> are not equal 2π

  - elements from the previous condition add to vector A

Department of Electromagnetic Field, CTU FEE, `miloslav.capek@fel.cvut.cz`

Logical operators: &&, ||

- in the case we need to compare scalar values only then "short-circuited" evaluation can be used

- evaluation keeps on going till a point where it makes no sense to continue
  - i.e. when evaluating

```
>> clear; clc;
>> a = true;
>> b = false;
>> a && b && c && d
```

… no problems with undefined variables `c`, `d`, because the evaluation is terminated earlier

- however:
  - terminated with error …

```
>> clear; clc;
>> a = true;
>> b = true;
>> a && b && c && d
```


Department of Electromagnetic Field, CTU FEE, miloslav.capek@fel.cvut.cz

Logical operators

150 s

- create a row vector in the interval from 1 to 20 with step of 3
  - create the vector filled with elements from the previous vector that are greater than 10 and at the same time smaller than 16; use logical operators

Department of Electromagnetic Field, CTU FEE, miloslav.capek@fel.cvut.cz

Logical operators

240 s

- create matrix `M = magic(3)` and find out using functions `all` and `any`
  - in which columns all elements are greater than 2
  - in which rows at least one element is greater than or equal to 8
  - whether the matrix A contains positive numbers only

$$\mathbf{A} = \begin{pmatrix} 8 & 1 & 6 \\ 3 & 5 & 7 \\ 4 & 9 & 2 \end{pmatrix}$$

$$\text{any}\begin{pmatrix} 0 & 1 & 1 \\ 1 & 1 & 0 \\ 0 & 1 & 1 \end{pmatrix} = \begin{pmatrix} 1 & 1 & 1 \end{pmatrix}, \quad \text{all}\begin{pmatrix} 0 & 1 & 1 \\ 1 & 1 & 0 \\ 0 & 1 & 1 \end{pmatrix} = \begin{pmatrix} 0 & 1 & 0 \end{pmatrix}, \quad \text{any}\left(\text{all}\begin{pmatrix} 0 & 1 & 1 \\ 1 & 1 & 0 \\ 0 & 1 & 1 \end{pmatrix}\right) = \text{any}\begin{pmatrix} 0 & 1 & 0 \end{pmatrix} = 1$$

Logical operators

240 s

- find out the result of following operation and interpret it

```
>> ~(~[1 2 0 -2 0])
```

- test whether variable *b* is not equal to zero and then test whether at the same time $a / b > 3$
  - following operation tests whether both conditions are fulfilled while avoiding division by zero!

Matrix indexation using own values

300 s

- create matrix `A`

```
>> N = 4;
>> A = magic(N)
```

```
A =

    16     2     3    13
     5    11    10     8
     9     7     6    12
     4    14    15     1
```

- first think about what will be the result of the following operation and only then carry it out

```
>> B = A(A)
```

  - does the result correspond to what you expected?
  - can you explain why the result looks the way it looks?
  - notice the interesting mathematical properties of the matrix `A` and `B`
  - are you able to estimate the evolution?, `C = B(B)`

- try similar process for `N = 3` or `N = 5`

Cell

- variable of type cell enables to store all types of variables (i.e. for instance variable of type cell inside another variable of type cell)
  - Examples of cell:

```
>> CL1 = {zeros(2),ones(3),rand(4),'test',{NaN(1),inf(2)}}
```

  - variable of type cell can be easily allocated:

```
>> CL0 = cell(1,3)
```

- memory requirements is a trade-off for complexity of cell type

Department of Electromagnetic Field, CTU FEE, miloslav.capek@fel.cvut.cz

Cell indexing #1

- there are two possible ways of cell structure indexing
  - round brackets **( )** are used to access cells as such
  - curly brackets **{ }** are used to access data in individual cells

- Example.:

```
>> CL = {[1 2;3 4];eye(3);'test'}
>> CL(2:3)      % returns cells 2, 3 of CL
>> CL{1}        % returns matrix  [1 2; 3 4]
>> CL{1}(2,1)   % = 3

>> CL1 = CL(1)  % CL1 is still a cell!
>> M   = CL1{1} % M is a matrix of numbers of type double
double
```


Department of Electromagnetic Field, CTU FEE, miloslav.capek@fel.cvut.cz

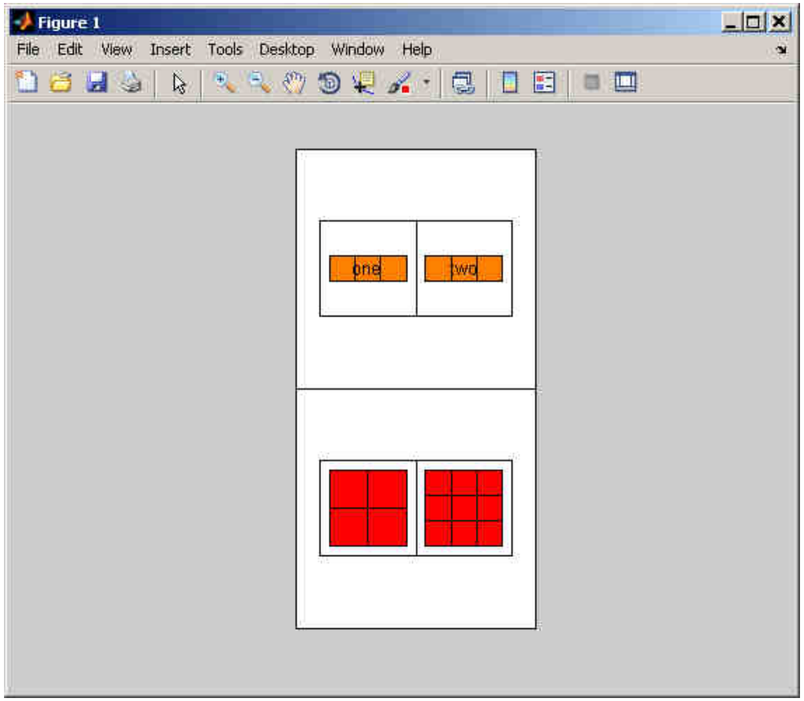
Cell indexing #2

- Example.:

```
>> CL1 = {'one','two'};
>> CL2 = {[1, 2; 3, 4],magic(3)};
>> CL  = {CL1; CL2};
>> CL{2}{1}(2,1)
```

- functions to get oriented in a cell

  - `celldisp`
  - `cellplot`




```
>> celldisp(CL)

CL{1}{1} =

one


CL{1}{2} =

two


CL{2}{1} =

     1     2
     3     4



CL{2}{2} =

     8     1     6
     3     5     7
     4     9     2
```

Typical application of cells

- in `switch-case` branching for enlisting more possibilities
- work with variously long strings
- GUI
- all iteration algorithms with variable size of variables
- …

Discussed functions

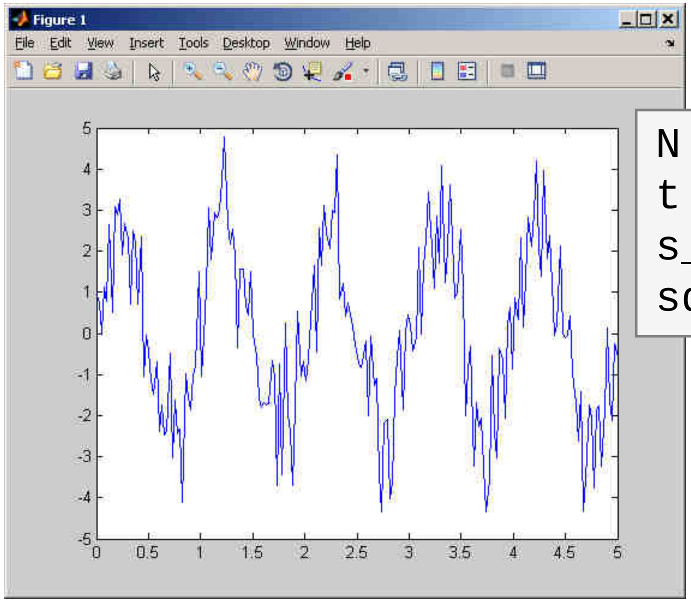
`edit`	open Matlab Editor	●
`keyboard`	stops execution ot the file and gives control to keyboard	●
`return, input`	return control to invoking function, value input request	●
`disp, pause`	display result in command line, pauses code execution	●
`num2str`	conversion from datatype `numeric` to `char`	●
`and, or, not, xor`	functions overloading logical operators	
`all, any`	evaluation of logical arrays („all of“, „at least one of“)	●
`sign`	signum function	

Exercise #1

360 s

- recall the signal from lecture 3
  - try again to limit the signal by values $s_{\min}$ a $s_{\max}$
  - use relational operators (`>` / `<`) and logical indexing (`s(a>b) = c`) instead of functions `max`, `min`
    - solve the task item-by-item

$$s_{\mathrm{p}}(t) = \begin{cases} s_{\min} \Leftrightarrow s(t) < s_{\min} \\ s_{\max} \Leftrightarrow s(t) > s_{\max} \\ s(t) \ \ldots \text{otherwise} \end{cases} \qquad s_{\min} = -\frac{9}{10} \qquad s_{\max} = \frac{\pi}{2}$$




```
N = 5; V = 40;
t = linspace(0, N, N*V);
s_t = randn(1, N*V) + ...
sqrt(2*pi)*sin(2*pi*t);
```

Exercise #2

300 s

- consider following matrix: $\mathbf{A} = \begin{pmatrix} 1 & 1 & 2 \\ 2 & 3 & 5 \end{pmatrix}$
- write a condition testing whether all elements of **A** are positive and at the same time all elements of the first row are integers
  - if the condition is fulfilled display the result using `disp`

Thank you!

ver. 6.1 (20/10/2016)

Miloslav Čapek, Pavel Valtr
miloslav.capek@fel.cvut.cz
Pavel.Valtr@fel.cvut.cz

Document created as part of A0B17MTB course.