A0B17MTB – Matlab

Part #7

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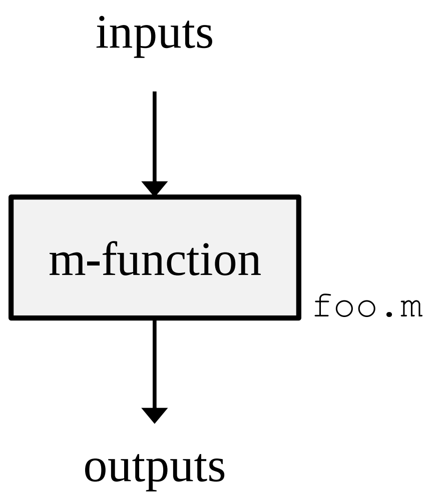
Learning how to …

Functions



Functions in Matlab

- more efficient, more transparent and faster than scripts
- defined input and output, comments → <u>function header</u> is necessary
- can be called from Command Window or from other function (in both cases the function has to be accessible)
- each function has its own work space created upon the function's call and terminated with the last line of the function

Function types by origin

- built-in functions
  - not accessible for editing by the user, available for execution
  - optimized and stored in core
  - usually frequently used (elementary) functions
- Matlab library functions ([`toolbox`] directory)
  - subject-grouped functions
  - some of them are available for editing (not recommended!)
- user-created functions
  - fully accessible and editable, functionality not guaranteed
  - mandatory parts: function header
  - recommended parts of the function: function description, characterization of inputs and outputs, date of last editing, function version, comments

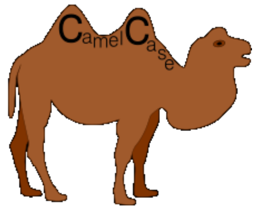
Function header

- ~~has to be the first line of a standalone file!~~ (Matlab 2017a+)
- square brackets `[]` for one output parameter are not mandatory
- function header has the following syntax:

```
function [out1, out2, ...] = functionName(in1, in2, ...)
```

keyword — function's output parameters — function's name — function's input parameters

- `functionName` has to follow the same rules as a variable's name
- `functionName` can't be identical to any of its parameters' name
- `functionName` is usually typed as `lowerCamelCase` or using underscore character (`my_function`)



Function header – examples

```
function functA
%FUNCTA - unusual, but possible, without input and output
```

```
function functB(parIn1)
%FUNCTB - e.g. function with GUI output, print etc.
```

```
function parOut1 = functC
%FUNCTC - data preparation, pseudorandom data etc.
```

```
function parOut1 = functD(parIn1)
%FUNCTD - „proper“ function
```

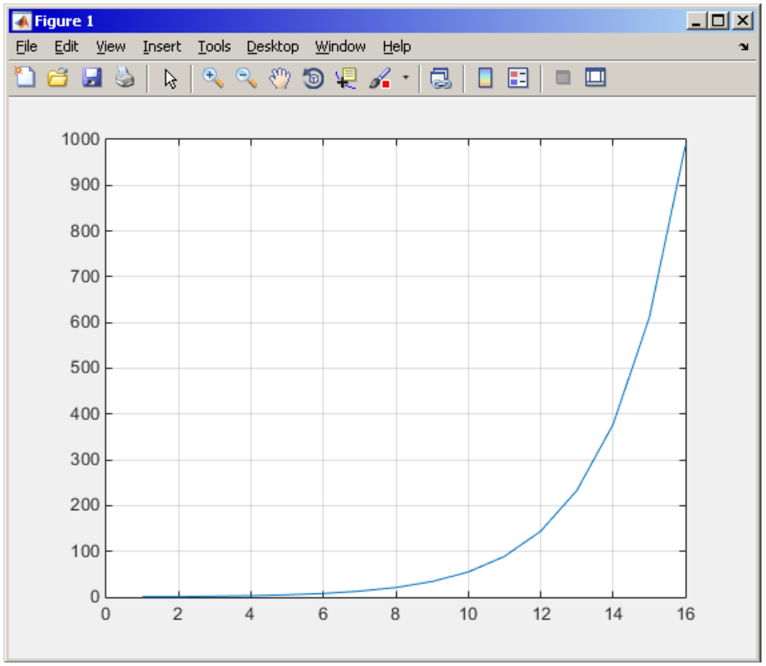
```
function parOut1 = functE(parIn1, parIn2)
%FUNCTE - proper function
```

```
function [parOut1, parOut2] = functF(parIn1, parIn2)
%FUNCTF - proper function with more parameters
```

Calling Matlab function

```
>> f = fibonacci(1000);  % calling from command prompt
>> plot(f); grid on;
```

```
function f = fibonacci(limit)
%% Fibonacci sequence
f = [1 1]; pos = 1;
while f(pos) + f(pos+1) < limit
    f(pos+2) = f(pos) + f(pos+1);
    pos = pos + 1;
end
end
```



- Matlab carries out commands sequentially
  - input parameter: `limit`
  - output variable: Fibonacci series `f`
  - drawbacks:
    - input is not treated (any input can be entered)
    - matrix `f` is not allocated, i.e. matrix keeps growing (slow)

Simple example of a function

- any function in Matlab can be called with less input parameters than stated in the header
- any function in Matlab can be called with less output parameters than stated in the header
  - for instance, consider following function:

```
function [parOut1, parOut2, parOut3] = functG(parIn1, parIn2, parIn3)
%FUNCTG - 3 inputs, 3 outputs
```

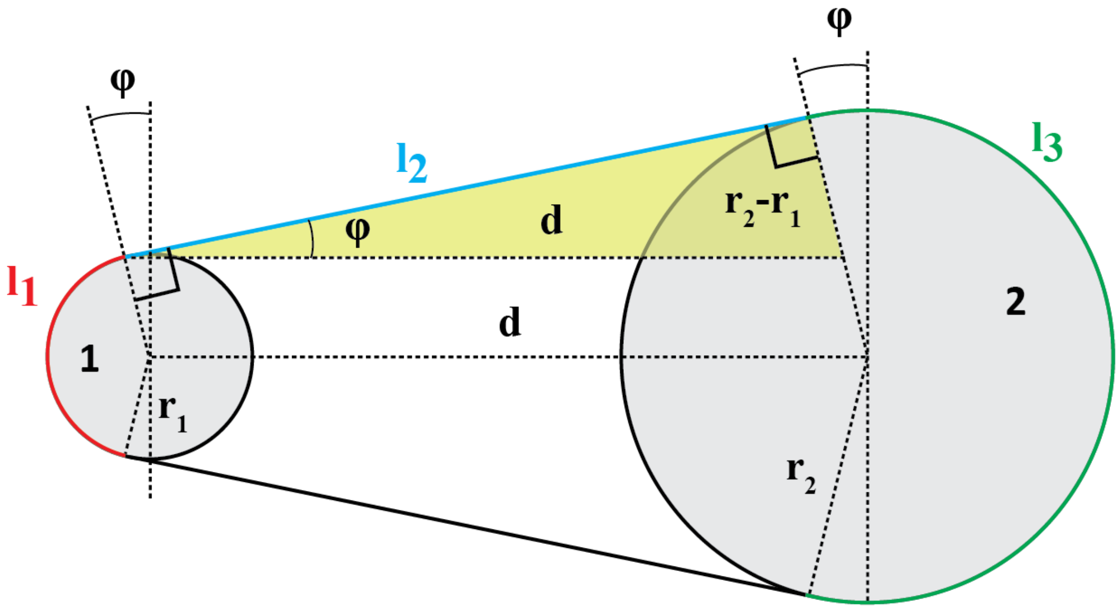
  - all following calling syntaxes are correct

```
>> [par01, par02]          = functG(pIn1, pIn2, pIn3)
>> [par01, par02, par03] = functG(pIn1)
>> functG(pIn1,pIn2,pIn3)
>> [par01, par02, par03] = functG(pIn1, pIn2, pIn3)
>> [par01, ~, par03] = functG(pIn1, [], pIn3)
>> [~, ~, par03] = functG(pIn1, [], [])
>> functG inputStr1 inputStr2
```

Simple example of a function

100 s

- propose a function to calculate length of a belt between two wheels
  - diameters of both wheels are known as well as their distance (= function's inputs)
  - sketch a draft, analyze the situation and find out what you need to calculate
  - test the function for some scenarios and verify results
  - comment the function, apply commands `doc`, `lookfor`, `help`, `type`

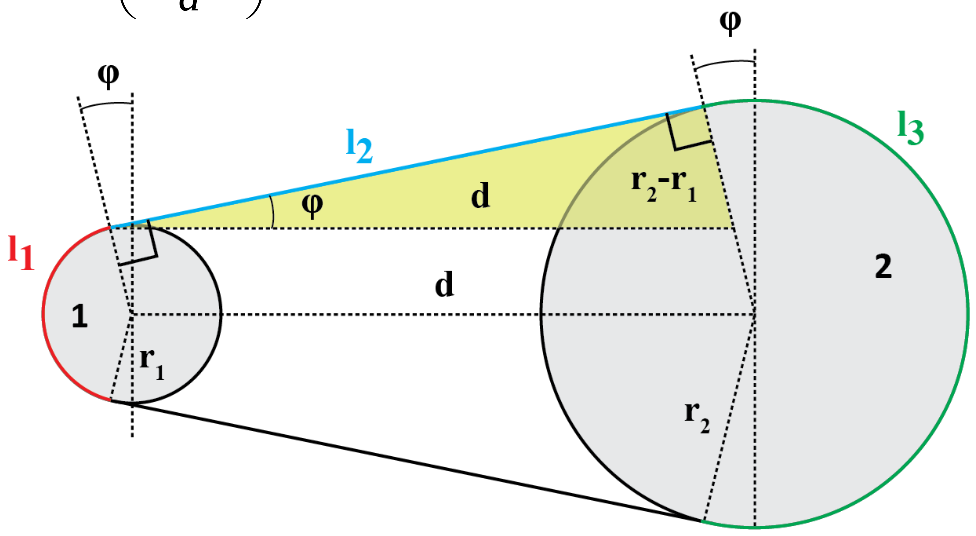


Simple example of a function

500 s

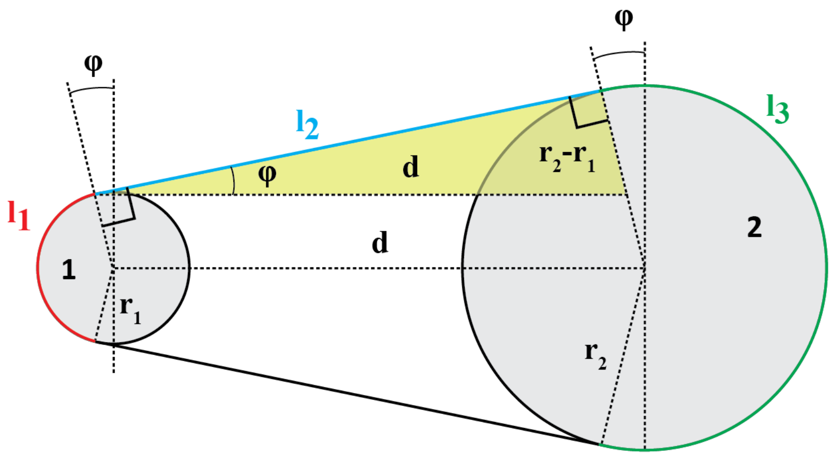
- total length is $l = l_1 + 2l_2 + l_3$
- known diameters ⟶ recalculate to radiuses $r_1 = d_1/2,\ r_2 = d_2/2$
- l_2 to be determined using Pythagorean theorem : $l_2 = \sqrt{d^2 - (r_2 - r_1)^2}$
- Analogically for φ: $\varphi = \operatorname{asin}\left(\frac{r_2 - r_1}{d}\right)$
- and finally : $l_1 = (\pi - 2\varphi) r_1$
  $l_3 = (\pi + 2\varphi) r_2$
- verify your results using

$$d_1 = 2,\ d_2 = 2,\ d = 5$$
$$L = \pi + 2 \cdot 5 + \pi \approx 16.2832$$



Simple example of a function

```
>> doc band_wheel
>> help band_wheel,
>> type band_wheel,
>> lookfor band_wheel,
```



Comments inside a function

function help, displayed upon:
`>> help myFcn1`

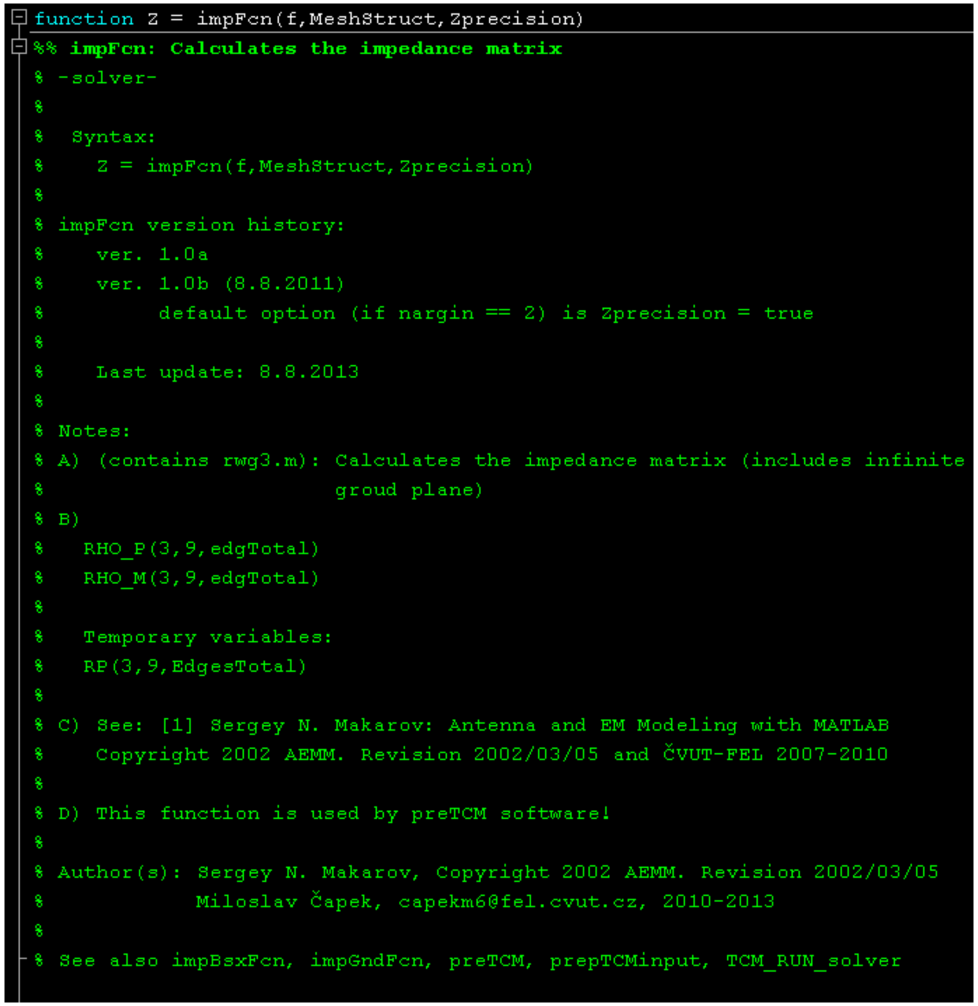
```
function [dataOut, idx] = myFcn1(dataIn, method)
%MYFCN1: Calculates...
% syntax, description of input, output,
% expamples of function's call, author, version
% other similar functions, other parts of help

matX = dataIn(:, 1);
sumX = sum(matX); % sumation
%% displaying the result:
disp(num2str(sumX));
```

1st line (so called H1 line), this line is searched for by `lookfor`. Usually contains function's name in capital characters and a brief description of the purpose of the function.

```
function pdetool(action, flag)
%PDETOOL PDE Toolbox graphical user interface (GUI).
%   PDETOOL provides the graphical user ...
```

```
DO COMMENT!
% Comments significantly improve
% transparency of functions' code !!!
```

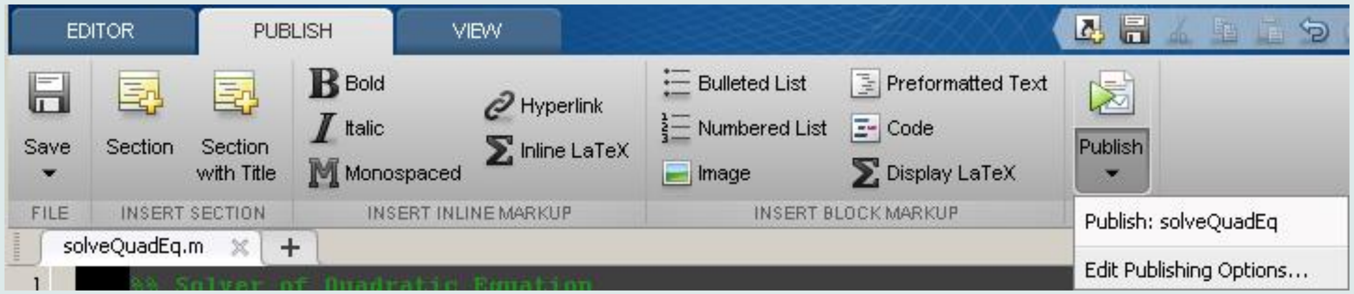
Function documentation – example



```
function Z = impFcn(f,MeshStruct,Zprecision)
%% impFcn: Calculates the impedance matrix
% -solver-
%
%  Syntax:
%    Z = impFcn(f,MeshStruct,Zprecision)
%
% impFcn version history:
%    ver. 1.0a
%    ver. 1.0b (8.8.2011)
%         default option (if nargin == 2) is Zprecision = true
%
%    Last update: 8.8.2013
%
% Notes:
% A) (contains rwg3.m): Calculates the impedance matrix (includes infinite
%                       groud plane)
% B)
%   RHO_P(3,9,edgTotal)
%   RHO_M(3,9,edgTotal)
%
%   Temporary variables:
%   RP(3,9,EdgesTotal)
%
% C) See: [1] Sergey N. Makarov: Antenna and EM Modeling with MATLAB
%    Copyright 2002 AEMM. Revision 2002/03/05 and ČVUT-FEL 2007-2010
%
% D) This function is used by preTCM software!
%
% Author(s): Sergey N. Makarov, Copyright 2002 AEMM. Revision 2002/03/05
%            Miloslav Čapek, capekm6@fel.cvut.cz, 2010-2013
%
% See also impBsxFcn, impGndFcn, preTCM, prepTCMinput, TCM_RUN_solver
```

Function `publish`

- serves to create script, function or class documentation
- provides several output formats (html, doc, ppt, LaTeX, ...)
- help creation (`>> doc my_fun`) directly in the code comments!
    - provides wide scale of formatting properties (titles, numbered lists, equations, graphics insertion, references, ...)
- enables to insert print screens into documentation
    - documented code is implicitly launched on publishing
- supports documentation creation directly from editor menu:

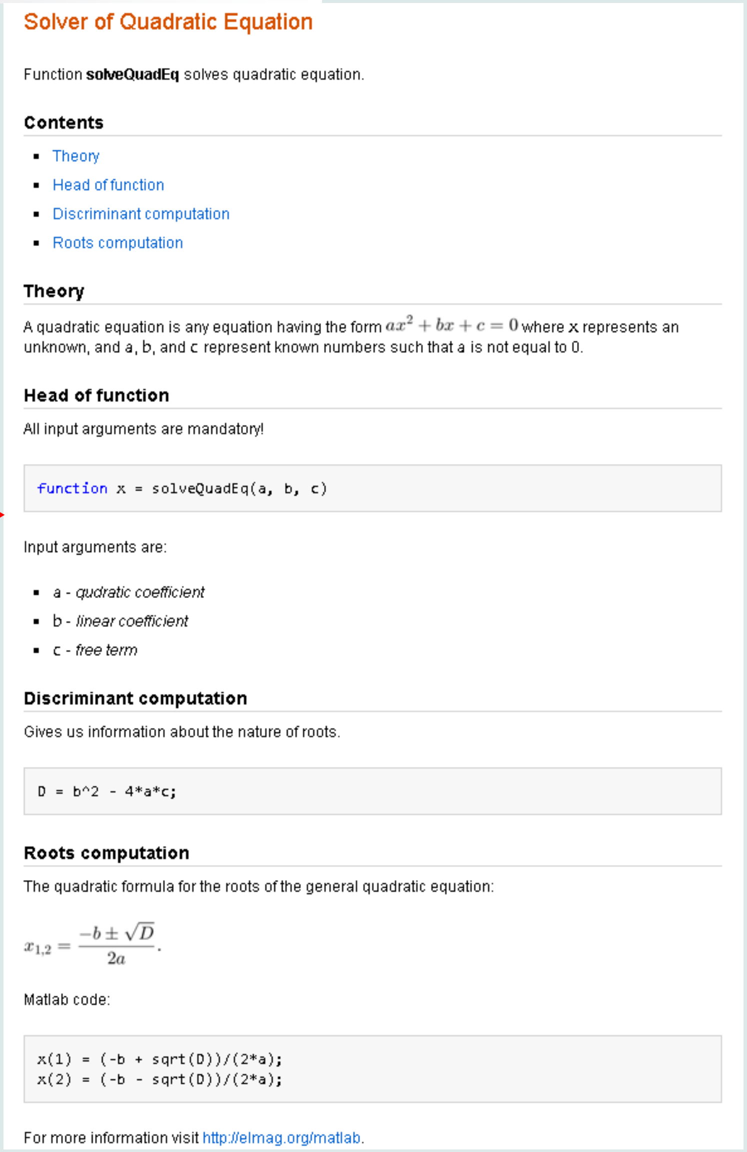


```
%% Solver of Quadratic Equation
```

Function `publish` - example

```
%% Solver of Quadratic Equation
% Function *solveQuadEq* solves quadratic equation.
%% Theory
% A quadratic equation is any equation having the form
% $ax^2+bx+c=0$
% where |x| represents an unknown, and |a|, |b|, and |c|
% represent known numbers such that |a| is not equal to 0.
%% Head of function
% All input arguments are mandatory!
function x = solveQuadEq(a, b, c)
%%
% Input arguments are:
%%
% * |a| - _qudratic coefficient_
% * |b| - _linear coefficient_
% * |c| - _free term_
%% Discriminant computation
% Gives us information about the nature of roots.
D = b^2 - 4*a*c;
%% Roots computation
% The quadratic formula for the roots of the general
% quadratic equation:
%
% $$x_{1,2} = \frac{ - b \pm \sqrt D }{2a}.$$
%
% Matlab code:
%%
x(1) = (-b + sqrt(D))/(2*a);
x(2) = (-b - sqrt(D))/(2*a);
%%
% For more information visit <http://elmag.org>.
```

$\xrightarrow{\text{publish}}$



Solver of Quadratic Equation

Function **solveQuadEq** solves quadratic equation.

Contents

- Theory
- Head of function
- Discriminant computation
- Roots computation

Theory

A quadratic equation is any equation having the form $ax^2+bx+c=0$ where x represents an unknown, and a, b, and c represent known numbers such that a is not equal to 0.

Head of function

All input arguments are mandatory!

```
function x = solveQuadEq(a, b, c)
```

Input arguments are:

- a - *qudratic coefficient*
- b - *linear coefficient*
- c - *free term*

Discriminant computation

Gives us information about the nature of roots.

```
D = b^2 - 4*a*c;
```

Roots computation

The quadratic formula for the roots of the general quadratic equation:

$$x_{1,2} = \frac{-b \pm \sqrt{D}}{2a}.$$

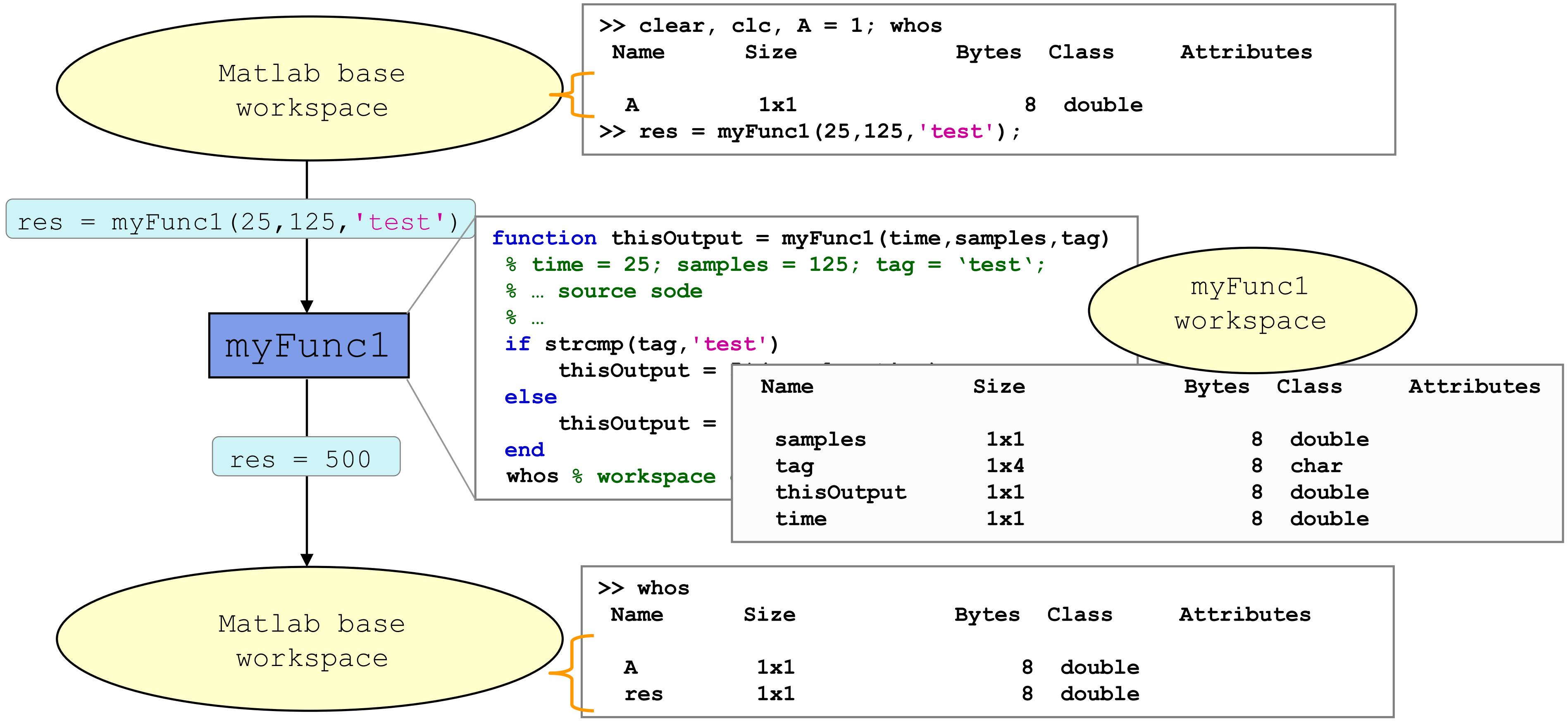
Matlab code:

```
x(1) = (-b + sqrt(D))/(2*a);
x(2) = (-b - sqrt(D))/(2*a);
```

For more information visit http://elmag.org/matlab.

Workspace of a function

- each function has its own workspace



```
>> clear, clc, A = 1; whos
 Name       Size                Bytes  Class     Attributes

  A          1x1                    8  double
>> res = myFunc1(25,125,'test');
```

```
function thisOutput = myFunc1(time,samples,tag)
 % time = 25; samples = 125; tag = 'test';
 % … source sode
 % …
 if strcmp(tag,'test')
        thisOutput =
 else
        thisOutput =
 end
 whos % workspace
```

```
 Name                Size                Bytes  Class     Attributes

  samples             1x1                    8  double
  tag                 1x4                    8  char
  thisOutput          1x1                    8  double
  time                1x1                    8  double
```

```
>> whos
 Name       Size                Bytes  Class     Attributes

  A          1x1                    8  double
  res        1x1                    8  double
```

Data space of a function #1

- on a function being called, input variables are not copied into workspace of the function, just their values are made accessible for the function (*copy-on-write technique*)
  - if an input variable is modified by the function, however, it is copied to the function's work space
  - with respect to memory saving and calculation speed-up it is advantageous to take corresponding elements out of a large array first and modify them rather than to modify the array directly and therefore evoke its copying in the function's workspace

- if the same variable is used as an input and output parameter it is immediately copied to the function's workspace
  - (provided that the input is modified in the script, otherwise the input and output variable is a reference to the same data)

Data space of a function #2

- all principles of programming covered at earlier stages of the course (operator overloading, data type conversion, memory allocation, indexing, etc.) apply to Matlab functions
  - in the case of overloading a built-in function, `builtin` is still applicable

- in the case of recursive function calling, own work space is created for each calling
  - pay attention to excessive increase of work spaces

- sharing of variables by multiple work spaces
  → global variables
  - by careful with how you use them (utilization of global variables is not recommended in general) and they are usually avoidable

Function execution

- when is function terminated?
  - Matlab interpreter reaches last line
  - interpreter comes across the keyword `return`
  - interpreter encounters an error (can be evoked by `error` as well)
  - on pressing CTRL+C

```
function res = myFcn2(matrixIn)

if isempty(matrixIn)
    error('matrixInCannotBeEmpty');
end
normMat = matrixIn - max(max(matrixIn));

if matrixIn == 5
    res = 20;
    return;
end
end
```

Number of input and output variables

- number of input and output variables is specified by functions `nargin` a `nargout`
- these functions enable to design the function header in a way to enable variable number of input/output parameters

```
function [out1, out2] = myFcn3(in1, in2)
nArgsIn = nargin;
if nArgsIn == 1
    % do something
elseif nArgsIn == 2
    % do something
else
    error('Bad inputs!');
end
% computation of out1
if nargout == 2
    % computation of out2
end
end
```

Number of input and output variables

500 s ↑

- modify the function `fibonacci.m` to enable variable input/output parameters :
  - it is possible to call the function without input parameters
    - the series is generated in the way that the last element is less than 1000
  - it is possible to call the function with one input parameter `in1`
    - the series is generated in the way that the last element is less than `in1`
  - it is possible to call the function with two input parameters `in1`, `in2`
    - the series is generated in the way that the last element is less than `in1` and at the same time the first 2 elements of the series are given by vector `in2`
  - it is possible to call the function without output parameters or with one output parameter
    - the generated series is returned
  - it is possible to call the function with two output parameters
    - the generated series is returned together with an object of class `Line`, which is plotted in a graph

```
hLine = plot(f);
```

Number of input and output variables

Syntactical types of functions

Function type	Description
main	the only one in the m-file visible from outside, above principles apply
local	all functions in the same file except the main function, accessed by the main function, has its own workspace, can be placed into `[private]` folder to preserve the private access, function in script file (2016b+)
nested	the function is placed inside the main function or local function, sees the WS of all superior functions
handle	function reference (`mySinX = @sin`)
anonymous	similar to handle functions (`myGoniomFcn = @(x) sin(x)+cos(x)`)
OOP	class methods with specific access, static methods

- any function in Matlab can launch a script which is then evaluated in the workspace of the function that launched it, not in the base workspace of Matlab (as usual)
- the order of local functions is not important (logical connection!)
- help of local functions is not accessible using `help`

Local functions

- local functions launched by main functions
  - all these functions can (should) be terminated with keyword `end`
  - are used for repeated tasks inside the main function (helps to simplify the problem by decomposing it into simple parts)
  - local functions "see" each other and have their own workspaces
  - are often used to process graphical elements events (callbacks) when developing GUI

```
function x = model_ITUR901(p,f)
% main function body
% ...
% ...
end

function y = calc_parTheta(q)
% function body
end
```

Local functions

- local functions launched by script (new from R2016b)
  - functions have to be at the end of file
  - all these functions have to be terminated with keyword `end`
  - local functions "see" each other and have their own workspaces
  - local function id not accessible outside the script file

```
clear;
% start of script
r = 0.5:5; % radii of circles
areaOfCirles = computeArea(r);

function A = computeArea(r)
% local function in script
A = pi*r.^2;
end
```

Nested functions

- nested functions are placed inside other functions
  - it enables us to use workspace of the parent function and to efficiently work with (usually small) workspace of the nested function
  - functions can not be placed inside conditional/loop control statements (`if`-`else`-`elseif` / `switch`-`case` / `for` / `while` / `try`-`catch`)

```
function x = A(p)
% single
% nested function
...
    function y = B(q)
     ...
    end
...
end
```

```
function x = A(p)
% more
% nested functions
...
    function y = B(q)
     ...
    end

    function z = C(r)
     ...
    end
...
end
```

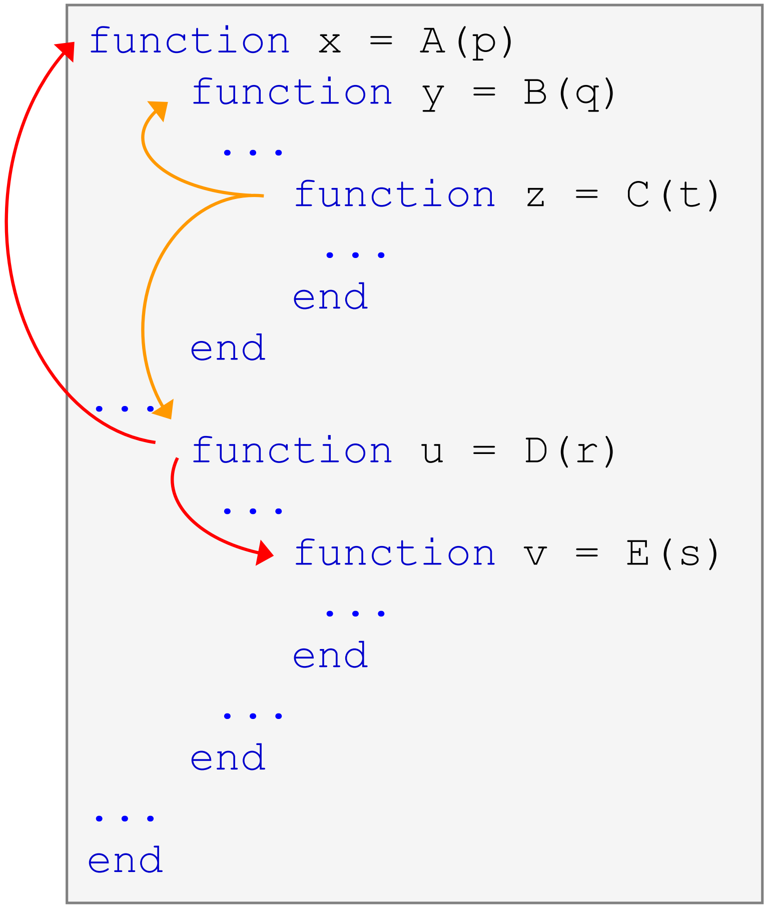
```
function x = A(p)
% multiple
% nested function
...
    function y = B(q)
     ...
       function z = C(r)
        ...
       end
     ...
    end
...
end
```

Nested functions: calling

- apart from its workspace, nested functions can also access workspaces of all functions it is nested in

- nested function can be called from:
  - its parent function
  - nested function on the same level of nesting
  - function nested in it

- it is possible to create handle to a nested function
  - see later

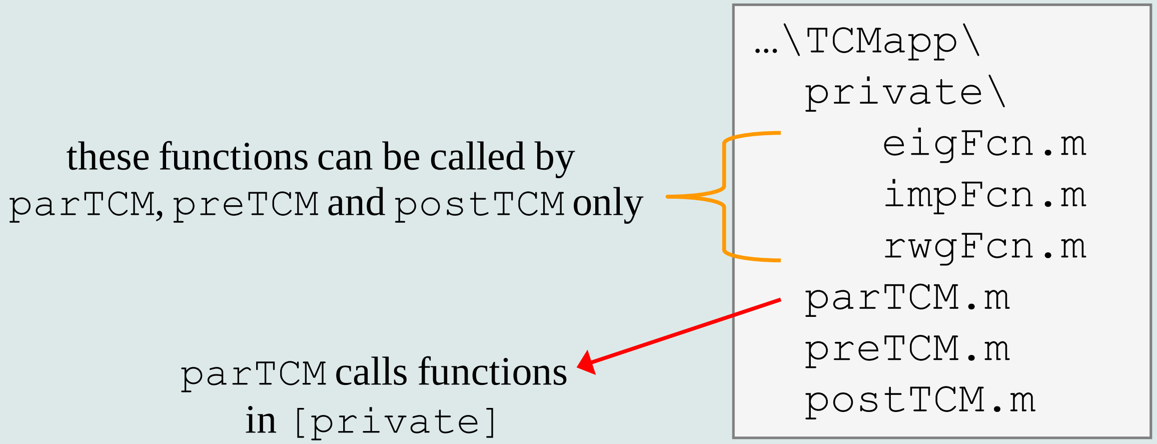


```
function x = A(p)
    function y = B(q)
     ...
        function z = C(t)
         ...
        end
    end
...
    function u = D(r)
     ...
        function v = E(s)
         ...
        end
     ...
    end
...
end
```

Private functions

- they are basically the local functions, and they can be called by all functions placed in the root folder
- reside in subfolder `[private]` of the main function

- private functions can be accessed only by functions placed in the folder immediately above that private subfolder
  - `[private]` is often used with larger applications or in the case where limited visibility of files inside the folder is desired



```
…\TCMapp\
  private\
     eigFcn.m
     impFcn.m
     rwgFcn.m
  parTCM.m
  preTCM.m
  postTCM.m
```

these functions can be called by parTCM, preTCM and postTCM only
parTCM calls functions in [private]

Handle functions

- it is not a function as such
- handle = reference to a given function
  - properties of a handle reference enable to call a function that is otherwise not visible
  - reference to a handle (here `fS`) can be treated in a usual way
- typically, handle references are used as input parameters of functions

```
>> fS = @sin; % handle creation
>> fS(pi/2)
ans =
     1
```

```
>> whos
 Name      Size            Bytes  Class              Attributes

  ans      1x1                 8  double
  fS       1x1                32  function_handle
```

Anonymous functions

- anonymous functions make it possible to create handle reference to a function that is not defined as a standalone file
  - the function has to be defined as one executable expression

```
>> sqr = @(x) x.^2; % create anonymous function (handle)
>> res = sqr(5);    % x ~ 5, res = 5^2 = 25;
```

  - anonymous function can have more input parameters

```
>> A = 4; B = 3; % parameters A,B have to be defined
>> sumAxBy = @(x, y) (A*x + B*y); % function definition
>> res2 = sumAxBy(5,7);     % x = 5, y = 7
% res2 = 4*5+3*7 = 20+21 = 41
```

  - anonymous function stores variables required as well as prescription

```
>> A = 4;
>> multAx = @(x) A*x;
>> clear A
>> res3 = multAx(2);
% res3 = 4*2 = 8
```

- `>> doc Anonymous Functions`

```
>> Fcn = @(hndl, arg) (hndl(arg))
>> res = Fcn(@sin, pi)
```

Anonymous functions – Example

500 s ↑

- create anonymous function $\mathbf{A}(p)=\begin{bmatrix} A_1(p) & A_2(p) & A_3(p) \end{bmatrix}$ so that

$$A_1(p)=\cos^2(p)$$
$$A_2(p)=\sin(p)+\cos(p)$$
$$A_3(p)=1$$

- calculate and display its components for $p=[0,2\pi]$

- check the function $\mathbf{A}(p)$ with Matlab built-in function functions, *i.e.*, `functions(A)`

Taylor series – script

600 s

- expand exponential function using Taylor series:
  - in this case it is in fact McLaurin series (expansion about 0)

$$e^x = \sum_{n=0}^{\infty} \frac{x^n}{n!} = 1 + x + \frac{x^2}{2} + \frac{x^3}{6} + \frac{x^4}{24} + \Lambda$$

  - compare with result obtained using `exp(x)`
  - find out the deviation in [%] (what is the base, i.e. 100% ?)
  - find out the order of expansion for deviation to be lower than 1%

  - implement the code as a script, enter :
    x (function argument)
    N (order of the series)

Taylor series – function

600 s

$$e^x = \sum_{n=0}^{\infty} \frac{x^n}{n!} = 1 + x + \frac{x^2}{2} + \frac{x^3}{6} + \frac{x^4}{24} + \Lambda$$

- implement as a function
  - choose appropriate name for the function
  - input parameters of the function are `x` and `N`
  - Output parameters are values `f1`, `f2` and `err`
  - add appropriate comment to the function (H1 line, inputs, outputs)

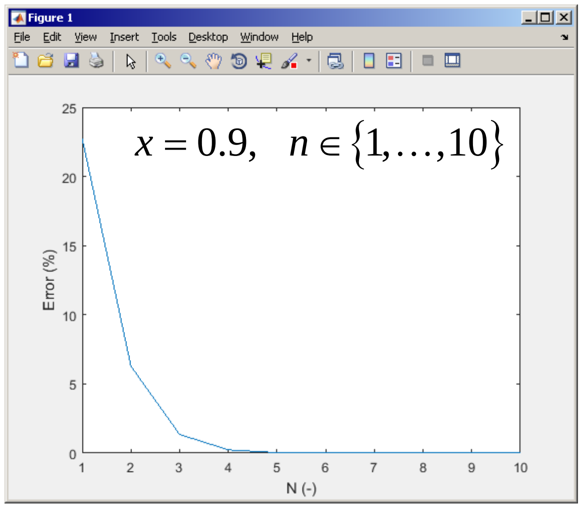
  - test the function

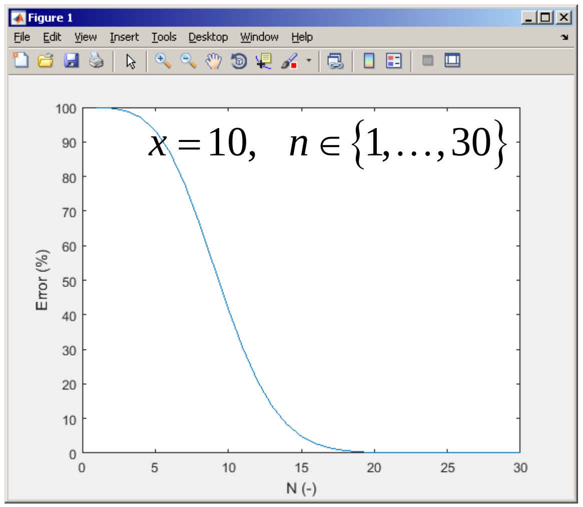
Taylor series – calling function

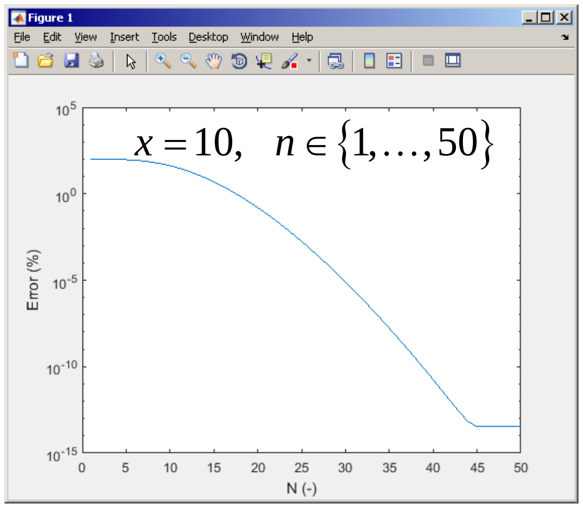
600 s

- create a script to call the above function (with various `N`)
  - find out accuracy of the approximation for $x = 0.9, \quad n \in \{1, \ldots, 10\}$
  - plot the resulting progress of the accuracy (error as a function of n)

Taylor series – results







Functions – advanced techniques

- in the case the number of input or output parameters is not known one can use `varargin` and `varargout`
  - function header has to be modified
  - input / output variables have to be obtained from `varargin` / `varargout`

```
function [parOut1, parOut2] = funcA(varargin)
%% variable number of input parameters
```

```
function varargout = funcB(parIn1, parIn2)
%% variable number of output parameters
```

```
function varargout = funcC(varargin)
%% variable number of input and output parameters
```

```
function [parOut1, varargout] = funcC(parIn1, varargin)
%% variable number of input and output parameters
```

`varargin` function

- typical usage: functions with many optional parameters / attributes
  - e.g. GUI (functions like `stem`, `surf` etc. include `varargin`)
- variable `varargin` is always of type `cell`, even when it contains just a single item
- function `nargin` in the body of a function returns the number of input parameters upon the function's call
- function `nargin(fx)` returns number of input parameters in function's header
  - when `varargin` is used in function's header, returns negative value

```
function plot_data(varargin)

nargin
celldisp(varargin)

par1 = varargin{1};
par2 = varargin{2};
% ...
end
```

Advanced Anonymous functions

- inline conditional:

```
>> iif = @(varargin) varargin{2*find([varargin{1:2:end}], ...
         1, 'first')}();
```

  - usage:

```
>> min10 = @(x) iif(any(isnan(x)), 'Don''t use NaNs', ...
                    sum(x) > 10, 'This is ok', ...
                    sum(x) < 10, 'Sum is low')
```

```
>> min10([1 10])  % ans = 'This is ok'
>> min10([1 nan]) % ans = 'Don't use NaNs'
```

- map:

```
>> map = @(val, fcns) cellfun(@(f) f(val{:}), fcns);
```

  - usage:

```
>> x = [3 4 1 6 2];
>> values = map({x}, {@min, @sum, @prod})
>> [extrema, indices] = map({x}, {@min, @max})
```

Variable number of input parameters

- input arguments are usually in pairs
- example of setting of several parameters to `line` object
- for all properties see
  `>> doc line`

```
>> plot_data(magic(3),...
        'Color',[.4 .5 .6],'LineWidth',2);
>> plot_data(sin(0:0.1:5*pi),...
        'Marker','*','LineWidth',3);
```

property	value
`Color`	[R G B]
`LineWidth`	0.1 – …
`Marker`	`'o'`, `'*'`, `'x'`, …
`MarkerSize`	0.1 – …
and others …	

```
function plot_data(data, varargin)
%% documentation should be here!

if isnumeric(data) && ~isempty(data)
    hndl = plot(data);
else
    fprintf(2, ['Input variable ''data''', ...
         'is not a numerical variable.']);
    return;
end

while length(varargin) > 1
    set(hndl, varargin{1}, varargin{2});
    varargin(1:2) = [];
end
end
```

varargout function

- variable number of output variables
- principle analogical to `varargin` function
  - bear in mind that function's output variables are of type `cell`
- used sporadically

```
function [s, varargout] = sizeout(x)
nout = max(nargout, 1) - 1;
s = size(x);
for k = 1:nout
   varargout{k} = s(k);
end
end
```

```
>>  [s, rows, cols] = sizeout(rand(4, 5, 2))
% s = [4 5 2], rows = 4, cols = 5
```

Output parameter `varargout`

180 s ↑

- modify the function `fibonacciFcn.m` so that it had only one output parameter `varargout` and its functionality was preserved

Expression evaluation in another WS

- function `evalin` („evaluate in“) can be used to evaluate an expression in a workspace that is different from the workspace where the expression exists
- apart from current workspace, other workspaces can be used as well
  - `'base'`: base workspace of Matlab
  - `'caller'`: workspace of parent function (from which the function was called)
- can not be used recursively

```
>> clear; clc;
>> A = 5;
>> vysl = eval_in
% res = 12.7976
```

```
function out = eval_in
%% no input parameters (A isn't known here)

k   = rand(1,1);
out = evalin('base', ['pi*A*', num2str(k)]);
end
```

Recursion

- Matlab supports recursion (function can call itself)
  - recursion is part of some useful algorithms (e.g. Adaptive Simpsons Method of integration)
- ver. R2014b and older:
  - the number of recursion is limited by 500 by default
  - the number of recursions can be changed, or get current setting:

```
>> set(0, 'RecursionLimit', 200)
>> get(0, 'RecursionLimit')
% ans = 200
```

- ver. R2015b and newer: recursion calling works until stack memory is not full
  - every calling creates new function's workspace!

Number of recursion steps

360 s

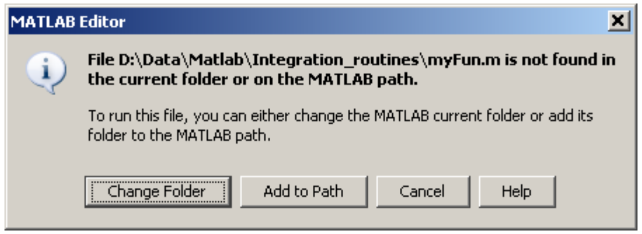
- write a simple function that is able to call itself; input parameter is `rek = 0` which is increased by 1 with each recursive step
  - display the increase of the value of `rek`
  - at what number does the increase stop
  - think over in what situations the recursion is necessary…

```
...
...
...
...
...
...
```

```
>> test_function(0)
```

Matlab `path`

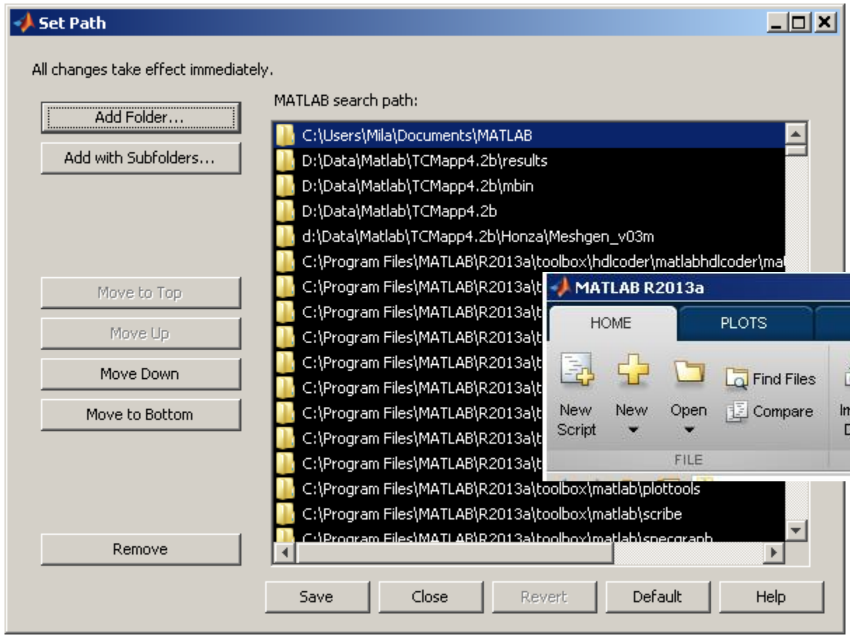
- list of directories seen by Matlab : `>> path`
- for more see `>> doc path`
- `addpath`: adds folder to path
- `rmpath`: removes folder from path



MATLAB Editor

File D:\Data\Matlab\Integration_routines\myFun.m is not found in the current folder or on the MATLAB path.

To run this file, you can either change the MATLAB current folder or add its folder to the MATLAB path.



Set Path

All changes take effect immediately.

MATLAB search path:

```
C:\Users\Mila\Documents\MATLAB
D:\Data\Matlab\TCMapp4.2b\results
D:\Data\Matlab\TCMapp4.2b\mbin
D:\Data\Matlab\TCMapp4.2b
d:\Data\Matlab\TCMapp4.2b\Honza\Meshgen_v03m
C:\Program Files\MATLAB\R2013a\toolbox\hdlcoder\matlabhdlcoder\mat
C:\Program Files\MATLAB\R2013a\t
C:\Program Files\MATLAB\R2013a\t
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C:\Program Files\MATLAB\R2013a\t
C:\Program Files\MATLAB\R2013a\t
C:\Program Files\MATLAB\R2013a\toolbox\matlab\plottools
C:\Program Files\MATLAB\R2013a\toolbox\matlab\scribe
C:\Program Files\MATLAB\R2013a\toolbox\matlab\specgraph
```
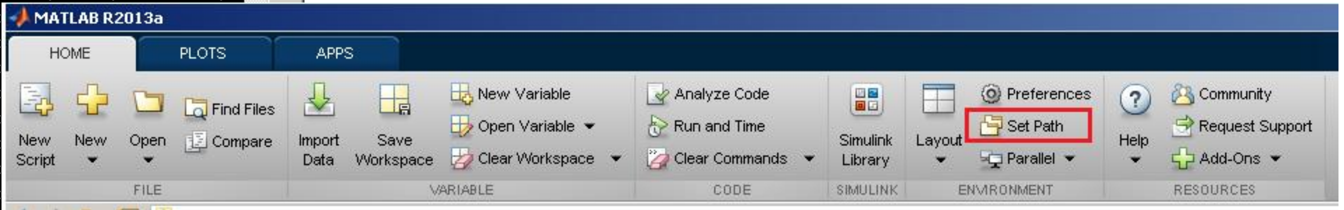



Calling a function – order

- how Matlab searches for a function (simplified):
  - it is a variable
  - function imported using `import`
  - nested or local function inside given function
  - private function
  - function (method) of a given class or constructor of the class
  - function in given folder
  - function anywhere within reach of Matlab (`path`)
- Inside a given folder is the priority of various suffixes as follows:
  - built-in functions
  - `mex` functions
  - `p`-files
  - `m`-files
- `doc Function Precedence Order`

Function vs. Command Syntax

- In Matlab exist two basic syntaxes how to call a function:

```
>> grid on      % Command syntax
>> % vs.
>> grid('on') % Function syntax
```

```
>> disp 'Hello Word!'  % Command syntax
>> % vs.
>> disp('Hello Word!') % Function syntax
```

- Command syntax
  - all inputs are taken as characters
  - outputs can't be assigned
  - input containing spaces has to be closed in single quotation marks

```
>> a = 1; b = 2;
>> plus a b % = 97 + 98
ans =
   195
>> p = plus a b % error
>> p = plus(a, b);
```

Class `inputParser` #1

- enables to easily test input parameters of a function
- it is especially useful to create functions with many input parameters with pairs `'parameter', value`
  - very typical for graphical functions

```
>> x = -20:0.1:20;
>> fx = sin(x)./x;
>> plot(x, fx, 'LineWidth', 3, 'Color', [0.3 0.3 1], 'Marker', 'd',...
 'MarkerSize', 10, 'LineStyle', ':')
```

- method `addParameter` enables to insert optional parameter
  - initial value of the parameter has to be set
  - the function for validity testing is not required
- method `addRequired` defines name of mandatory parameter
  - on function call it always has to be entered at the right place

Class `inputParser` #2

- following function plots a circle or a square of defined size, color and line width

```
function drawGeom(dimension, shape, varargin)
p = inputParser; % instance of inputParser
p.CaseSensitive = false; % parameters are not case sensitive
defaultColor = 'b'; defaultWidth = 1;
expectedShapes = {'circle', 'rectangle'};
validationShapeFcn = @(x) any(ismember(expectedShapes, x));
p.addRequired('dimension', @isnumeric); % required parameter
p.addRequired('shape', validationShapeFcn); % required parameter
p.addParameter('color', defaultColor, @ischar); % optional parameter
p.addParameter('linewidth', defaultWidth, @isnumeric) % optional parameter
p.parse(dimension, shape, varargin{:}); % parse input parameters

switch shape
   case 'circle'
      figure;
      rho = 0:0.01:2*pi;
      plot(dimension*cos(rho), dimension*sin(rho), ...
         p.Results.color, 'LineWidth', p.Results.linewidth);
      axis equal;
   case 'rectangle'
      figure;
      plot([0 dimension dimension 0 0], ...
         [0 0 dimension dimension 0], p.Results.color, ...
         'LineWidth', p.Results.linewidth)
      axis equal;
end
```

Function `validateattributes`

- checks correctness of inserted parameter with respect to various criteria
  - it is often used in relation with class `inputParser`
  - check whether matrix is of size 2x3, is of class `double` and contains positive integers only:

```
A = [1 2 3;4 5 6];
validateattributes(A, {'double'}, {'size',[2 3]})
validateattributes(A, {'double'}, {'integer'})
validateattributes(A, {'double'}, {'positive'})
```

  - it is possible to use notation where all tested classes and attributes are in one cell :

```
B = eye(3)*2;
validateattributes(B, {'double', 'single', 'int64'},...
    {'size',[3 3], 'diag', 'even'})
```

- for complete list of options >> `doc validateattributes`

Original names of input variables

- function `inputname` makes it possible to determine names of input parameters ahead of function call
  - consider following function call :

```
>> y = myFunc1(xdot, time, sqrt(25));
```

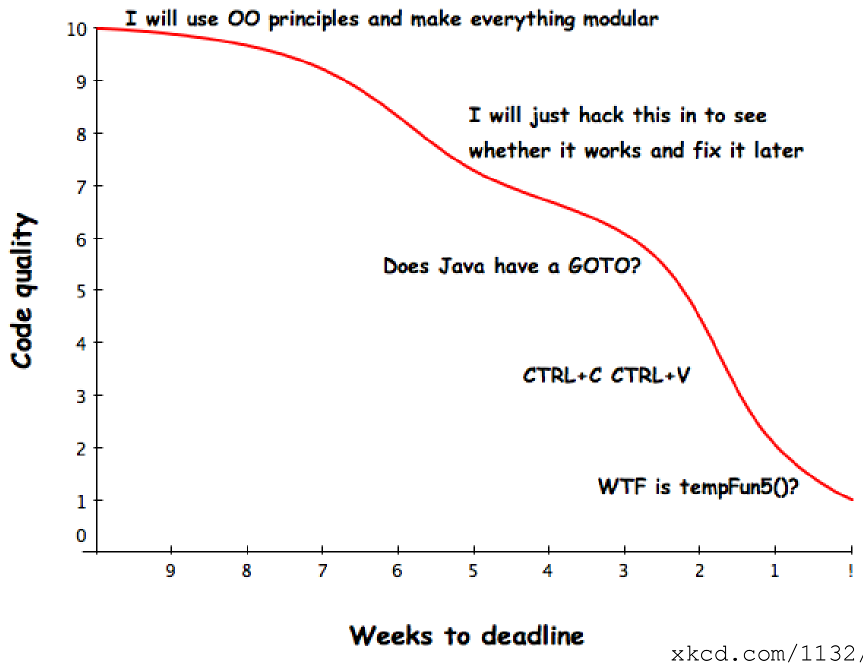
  - and then inside the function:

```
function output = myFunc1(par1, par2, par3)

% ...
p1str = inputname(1);     % p1str = 'xdot';
p2str = inputname(2);     % p2str = 'time';
P3str = inputname(3);     % p3str = '';
% ...
```

Function creation – advices

- viewpoint of efficiency – the more often a function is used, the better its implementation should be
  - code scaling
  - it is appropriate to verify input parameters
  - it is appropriate to allocate provisional output parameters
  - debugging
  - optimization of function time

- principle of code fragmentation – in the ideal case each function should solve just one thing; each problem should be solved just once



xkcd.com/1132/

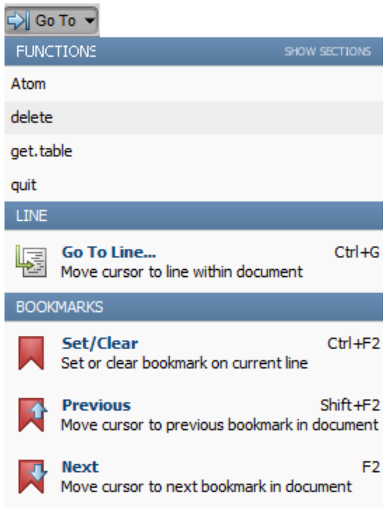
Selected advices for well arranged code

- ideally just one degree of abstraction
- code duplicity prevention
- function and methods should
  - solve one problem only, but properly
  - be easily and immediately understandable
  - be as short as possible
  - have the least possible number of input variables (< 3)

- further information:
  - Martin: Clear Code (Prentice Hall)
  - McConnell: Code Complete 2 (Microsoft Press)
  - Johnson: The Elements of Matlab Style (Cambridge Press)
  - Altman: Accelerating Matlab Performance (CRC)

Useful tools for long functions

- bookmarks
  - CTRL+F2 (add / remove bookmark)
  - F2 (next bookmark)
  - SHIFT+F2 (previous bookmark)
- Go to...
  - CTRL+G (go to line)
- long files can be split
  - same file can be opened e.g. twice



Atom
delete
get.table
quit

LINE

Go To Line... Ctrl+G
Move cursor to line within document

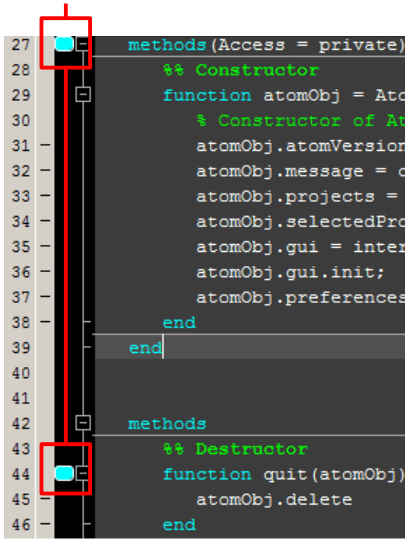
BOOKMARKS

Set/Clear Ctrl+F2
Set or clear bookmark on current line

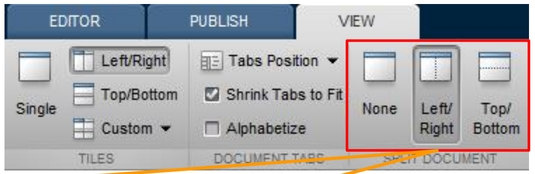
Previous Shift+F2
Move cursor to previous bookmark in document

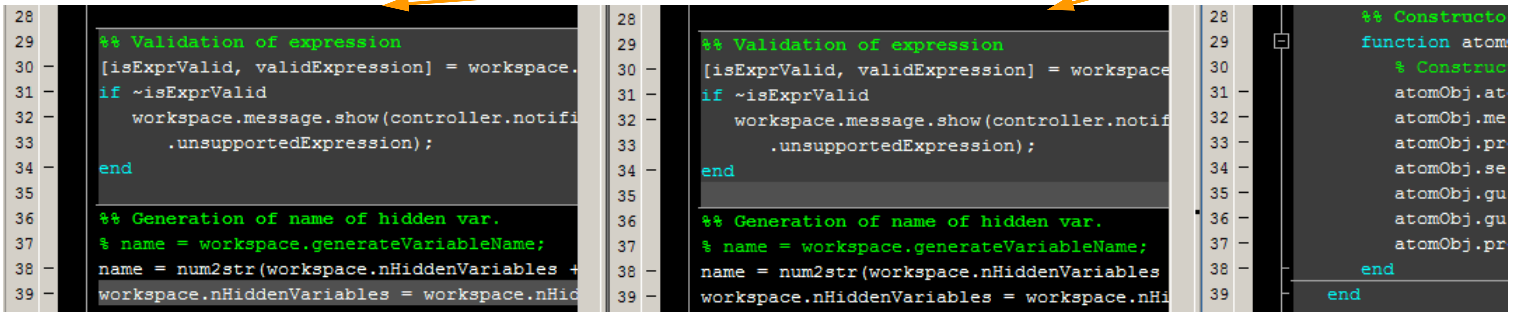
Next F2
Move cursor to next bookmark in document

bookmarks



```
methods (Access = private)
    %% Constructor
    function atomObj = Atc
        % Constructor of At
        atomObj.atomVersion
        atomObj.message = c
        atomObj.projects =
        atomObj.selectedPro
        atomObj.gui = inter
        atomObj.gui.init;
        atomObj.preferences
    end
end


methods
    %% Destructor
    function quit(atomObj)
        atomObj.delete
    end
```





```

%% Validation of expression
[isExprValid, validExpression] = workspace.
if ~isExprValid
    workspace.message.show(controller.notifi
        .unsupportedExpression);
end

%% Generation of name of hidden var.
% name = workspace.generateVariableName;
name = num2str(workspace.nHiddenVariables +
workspace.nHiddenVariables = workspace.nHid
```

```

%% Validation of expression
[isExprValid, validExpression] = workspace
if ~isExprValid
    workspace.message.show(controller.notif
        .unsupportedExpression);
end

%% Generation of name of hidden var.
% name = workspace.generateVariableName;
name = num2str(workspace.nHiddenVariables
workspace.nHiddenVariables = workspace.nHi
```

```
        %% Constructo
        function atom
            % Construc
            atomObj.at
            atomObj.me
            atomObj.pr
            atomObj.se
            atomObj.gu
            atomObj.gu
            atomObj.pr
        end
    end
```

Discussed functions

`function`	key word to create Matlab function
`@`	handle, anonymous function
`varargin, varargout`	variable number of input / output variables
`evalin, assignin`	evaluation of a command / assignment in another workspace
`inputname`	names of input variables in parent's workspace

Exercise #1 - notes

- find the unknown x in equation $f(x)=0$ using Newton's method

- typical implementation steps:
  (1) mathematical model
    - seize the problem, its formal solution

  (2) pseudocode
    - layout of consistent and efficient code

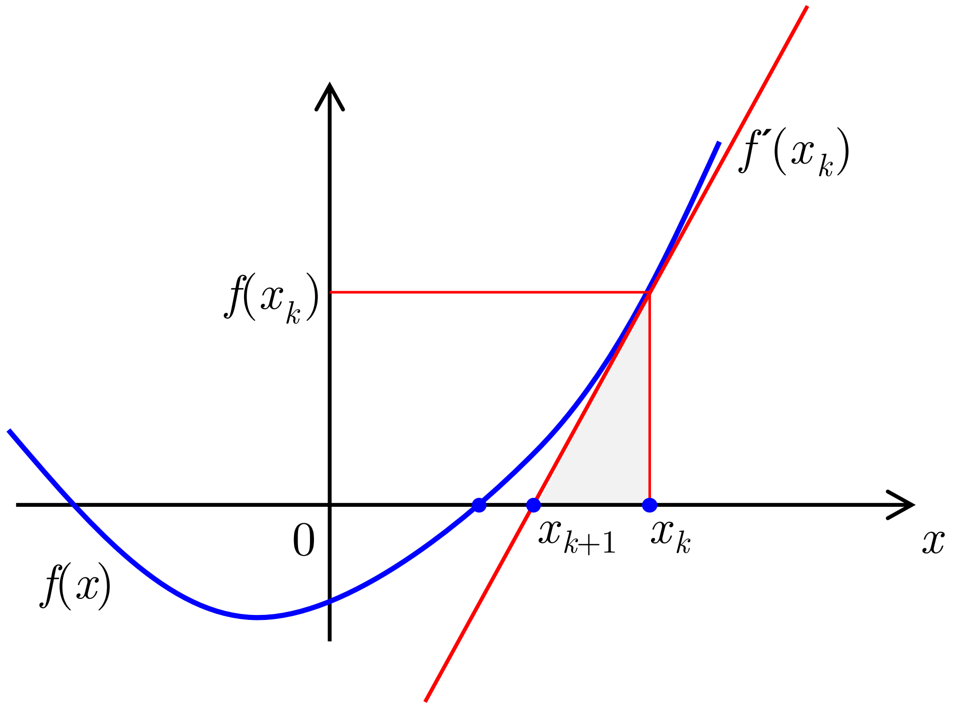
  (3) Matlab code
    - transformation into Matlab's syntax

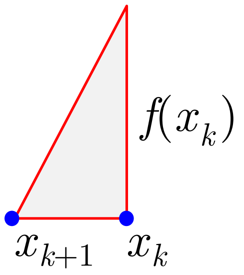
  (4) testing
    - usually using a problem with known (analytical) solution
    - try other examples...

Exercise #2

- find the unknown x in equation of type $f(x) = 0$
  - use Newton's method

- Newton's method:





$$f'(x_k) = \frac{\Delta f}{\Delta x} \approx \frac{\mathrm{d}f}{\mathrm{d}x}$$

$$f'(x_k) = \frac{\Delta f}{\Delta x} = \frac{f(x_k) - 0}{x_k - x_{k+1}}$$

$$x_{k+1} = x_k - \frac{f(x_k)}{f'(x_k)}$$

Exercise #3

- find the unknown x in equation $f(x)=0$ using Newton's method
- pseudocode draft:

```
(1) until $|(x_k - x_{k-1})/x_k| \geq err$ and simultaneously $k < 20$ do:
(2) $x_{k+1} = x_k - \frac{f(x_k)}{f'(x_k)}$
(3) disp([$k \quad x_{k+1} \quad f(x_{k+1})$])
(4) $k = k + 1$
```

- pay attention to correct condition of the (`while`) cycle
- create a new function to evaluate $f(x_k)$, $f'(x_k)$
- use following numerical difference scheme to calculate $f'(x_k)$:

$$f'(x_k) \approx \Delta f = \frac{f(x_k+\Delta) - f(x_k-\Delta)}{2\Delta}$$

Exercise #4

600 s ↑

- find the unknown x in equation $f(x)=0$ using Newton's method
  - implement the above method in Matlab to find the unknown x in $x^3+x-3=0$
  - the method comes in the form of a script calling following function :

```
clear; close all; clc;

% enter variables
% xk, xk1, err, k, delta

while cond1 and_simultaneously cond2
    % get xk from xk1
    % calculate f(xk)
    % calculate df(xk)
    % calculate xk1
    % display results
    % increase value of k
end
```

```
function fx = optim_fcn(x)

fx = x^3 + x - 3;

end
```

Exercise #5

- what are the limitations of Newton's method
  - in relation with existence of multiple roots
- is it possible to apply the method to complex values of x?

Exercise #6

600 s

- modify Newton's method in the way that the polynomial is entered in the form of a handle function
  - verify the code by finding roots of following polynomials :

$$x-2=0,\quad x^2=1$$

  - verify the result using function `roots`

Exercise #7

600 s

- using `integral` function calculate integral of current $Q = \int I(t)dt$ in the interval $t \in \langle 0,1 \rangle$s. The current has following time dependency, where $f = 50$ Hz

$$I\left(t\right) = 10\cos\left(2\pi f t\right) + 5\cos\left(4\pi f t\right)$$

  - solve the problem using handle function

  - using anonymous function

Thank you!

ver. 9.1 (04/04/2017)
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