AE0B17MTB – Matlab

Part #11

Miloslav Čapek
miloslav.capek@fel.cvut.cz

Filip Kozák, Viktor Adler, Pavel Valtr

Department of Electromagnetic Field
B2-626, Prague

Learning how to …

Data types `struct`, `categorical`, `table`

Import / export in Matlab

Time functions

`warning`, `error`, `try-catch`

Basics of symbolic math

$$I = \iint_S f(x,y)\,\mathrm{d}S \qquad f(x,y) = x + y$$

$$x \in (0,2),$$

$$y \geq 0 \wedge y \leq 2 - x$$

Structured variable, `struct`

- data are stored in variables that are grouped in one structure
- concept is similar to OOP (without features of OOP)

- Ex. inventory:

```
>> stock(1).id = 1;
>> stock(1).thing = 'fridge';
>> stock(1).price = 750;
>> stock(1).units = 'USD';
>> stock(2).id = 2;
>> stock(2).thing = 'Bowmore_12yr';
>> stock(2).price = 1100;
>> stock(2).units = 'CZK';
>> stock
```


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Functions for work with structures

- new field creation
  - direct command

```
>> stock(1).newField = 'test';
```

  - field name as a string

```
>> setfield(stock(1), 'newField', 'test');
```

- setting field value
  - direct command

```
>> stock(1).id = 3;
```

  - field name and value

```
>> stock(1).('id') = 3;
```

Functions for work with structures


```
>> fieldnames(stock)

ans =

    'id'
    'thing'
    'price'
    'units'
    'test'
```

- list of all fields of structure – `fieldnames`

```
>> fieldnames(stock)
```

- value of given field

```
>> id2 = stock(2).id
>> id2 = stock(2).('id')
>> id2 = getfield(stock(2), 'id')
```

- does given field exist?

```
>> isfield(stock, 'id')   % = 1
>> isfield(stock, 'ID')   % = 0
```

- is given variable a structure?

```
>> isstruct(stock)        % = 1
```

Functions for work with structures

- delete field

```
>> rmfield(stock, 'id')
```

- more complex indexing of structures
  - structure may have more levels

```
>> stock(1).subsection(1).order = 1
>> stock(1).subsection(2).order = 2
```

  - it is possible to combine cells with structures

```
>> stock(1).subsection(3).check = [1; 2]
>> K{1} = stock;
```

  - certain fields can be indexed using name stored as a string

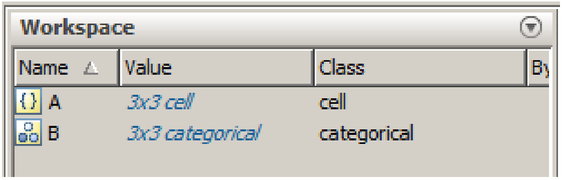
```
>> K{1}(1).subsection(3).('check')(2)
```

Typical application of structure

- export of data to Matlab
- all complex internal variables (exceptions, errors, ...)
- `callbackdata` (`event`) wit GUI

Data type, `categorical arrays`

- array of qualitative data with values from finite set of discrete non-numerical data
  - array of non-numerical values corresponding to a category (e.g. to the category 'mean of transport' correspond following values: scooter, wheelbarrow ...)
  - values can be specified by name (e.g. values `'r'`, `'g'`, `'b'`, they can be an attribute for name `'red'`, `'green'`, `'blue'`)
  - `categorical arrays` has its own icon in `Workspace`



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Creation of `categorical arrays`

- creation of `categorical array` from an arbitrary array of values (e.g. `cell array` of strings)

```
>> A = {'r' 'b' 'g'; 'g' 'r' 'b'; 'b' 'r' 'g'} % cell array of strings
>> B = categorical(A)    % categorical arrays
>> categories(B)         % listing of individual categories
```

- wide range of tools for combining, adding, removing, renaming, arranging,…

```
>> doc categorical arrays
```


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Advantages of `categorical arrays`

- more natural arranging of data by names
  - note: as in numerical arrays, logical operator `eq` (==) is used to compare strings in `categorical arrays` instead of function `strcmp()` used with strings
- mathematical arranging of strings
  - setting „size“ of string in other than alphabetical manner (e.g. `small < medium < large`)
- memory is used efficiently to store data
  - data in memory is not stored as string
  - only categories are stored as string in memory

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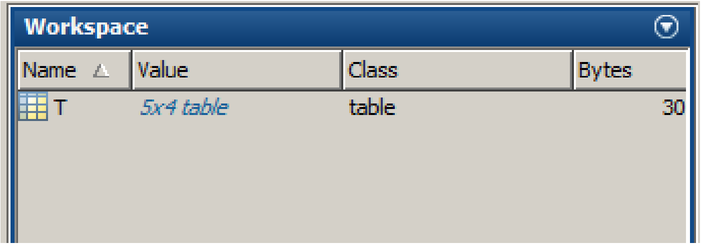
Data type `tables`

- array in form of a table that enables to have columns of various data types and sizes (silimar to `cell array`)
  - each column has to have the same number of lines (same as matrix)
  - `tables` have its own icon in `Workspace`



Creation of `tables`

- created by inserting individual vectors as columns of the table (same length of all vectors has to be observed)

```
>> name = {'Miloslav'; 'Filip'; 'Viktor'; 'Pavel'};
>> matlabSemester = [3; 3; 2; 1];
>> favoriteDrink = categorical({'b'; 'm'; 'w'; 'w'}, ...
       {'w'; 'm'; 'b'}, ...
       {'water'; 'milk'; 'beer'});

>> T = table(matlabSemester, favoriteDrink, 'RowNames', name)
```

- more `>> doc tables array`

```
T =

                semester    favoriteDrink
                ________    _____________

    Miloslav    3           beer
    Filip       3           milk
    Viktor      2           water
    Pavel       1           water
```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Advantages of `tables`

- advantageous way of storing data of various data types
- access to data via numerical and name indexing
  - e.g. listing all „Smiths“ in the table and display their „age“
- possibility to store metadata in table’s properties
  - e.g. for column „age“ it is possible to set unit to „year“

Data Import and export

- Matlab supports wide range of file formats
  - `mat`, `txt`, `xls`, `jpeg`, `bmp`, `png`, `wav`, `avi` and others, see
    - Matlab → Data and File Management → Data Import and Export → Import and Export Basics
  - packages exist for work with, for instance, `dwg` and similar formats
  - it is possible to read a general file containing ASCII characters as well

- in this course we shall see how to
  - read data from file, read image, read files line by line
  - store in file, write in file
  - import from Excel
  - export to Excel

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Data Import and export

- following can be applied to whole group of formats
  - old Matlab: use `File` → `Import Data`
  - new Matlab: `Home` → `Import Data`

  - command `uiimport` + following interface
  - file drag and drop to Workspace window

- for storing in various formats see following functions
  - `save`, `dlmwrite`, `xlswrite`, `imwrite`, `audiowrite`, `VideoWriter`

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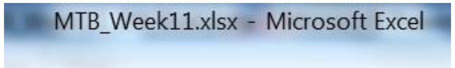
Import from Excel

- use funcrion `xlsread` to import
  - alternativelly, use aforementioned function `uiimport`

```
>> num = xlsread('MTB_Week11.xls', 'MyData', 'A1:B4');
```

File name
(has to be visible to Matlab)



name of the file's sheet

range of cells

	A	B	C	D
1	1000	1.1		
2	2000	1.2		
3	3000	1.4		
4	4000	1.4		
5				
6				
7				
8				

Import from Excel

420 s

- read all numerical data from Excel file on course's webpage
  - thereafter plot dependence of values in column `values` on values in column `experiment`
  - verify the size of data read

Export to Excel

- function `xlswrite` is used to export data from Matlab to Excel
  - example: write data `fx` in file `file.xlsx` in sheet `Sheet1` in line 1 starting with column `A`

```
>> fx = 1:10;
>> xlswrite('file.xlsx', fx, 1, 'A1');
```

  - example: write data `fx` in file `file2.xlsx` in sheet `NewSheet` in column `B` starting with line 1

```
>> fx = 1:10;
>> xlswrite('file2.xlsx', fx', 'NewSheet', 'B1');
```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Export to Excel

420 s ↑

- evaluate function $f(x) = \cos(x) + \frac{\cosh(x)}{10}$ on the interval $x \in \langle -\pi, \pi \rangle$ with step 0.01
  - resulting variables *x* and *f*(*x*) write to file `Excel_file.xlsx` in 1st sheet, variable *x* is in column `A`, variable *f*(*x*) is in column `B`
  - verify whether data written in the sheet are correct

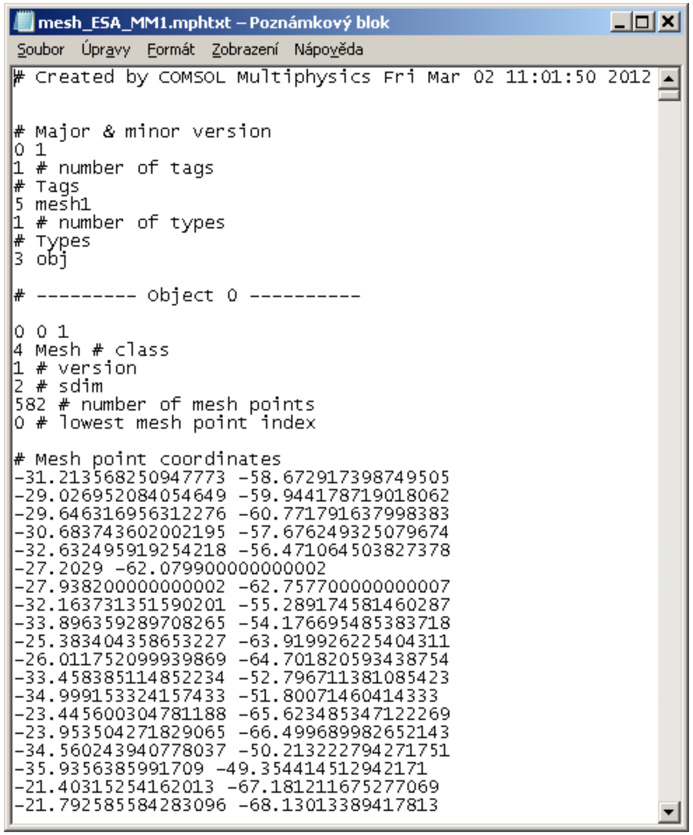
Reading binary data from file #1

- we will be using what we learned earlier (`while`, `str2double`, …)
  - on top of that the file has to be opened (`fopen`) and closed afterwards (`fclose`)

```
>> fid = fopen('mesh_ESA_MM1.mphtxt');
```

```
% allocation
while ~feof(fid)
    % reading
end
```

```
>> fclose(fid);
```


mesh_ESA_MM1.mphtxt – Poznámkový blok

Soubor Úpravy Formát Zobrazení Nápověda

```
# Created by COMSOL Multiphysics Fri Mar 02 11:01:50 2012


# Major & minor version
0 1
1 # number of tags
# Tags
5 mesh1
1 # number of types
# Types
3 obj

# --------- Object 0 ----------

0 0 1
4 Mesh # class
1 # version
2 # sdim
582 # number of mesh points
0 # lowest mesh point index

# Mesh point coordinates
-31.213568250947773 -58.672917398749505
-29.026952084054649 -59.944178719018062
-29.646316956312276 -60.771791637998383
-30.683743602002195 -57.676249325079674
-32.632495919254218 -56.471064503827378
-27.2029 -62.079900000000002
-27.938200000000002 -62.757700000000007
-32.163731351590201 -55.289174581460287
-33.896359289708265 -54.176695485383718
-25.383404358653227 -63.919926225404311
-26.011752099939869 -64.701820593438754
-33.458385114852234 -52.796711381085423
-34.999153324157433 -51.80071460414333
-23.445600304781188 -65.623485347122269
-23.953504271829065 -66.499689982652143
-34.560243940778037 -50.213222794271751
-35.9356385991709 -49.354414512942171
-21.40315254162013 -67.181211675277069
-21.792585584283096 -68.13013389417813
```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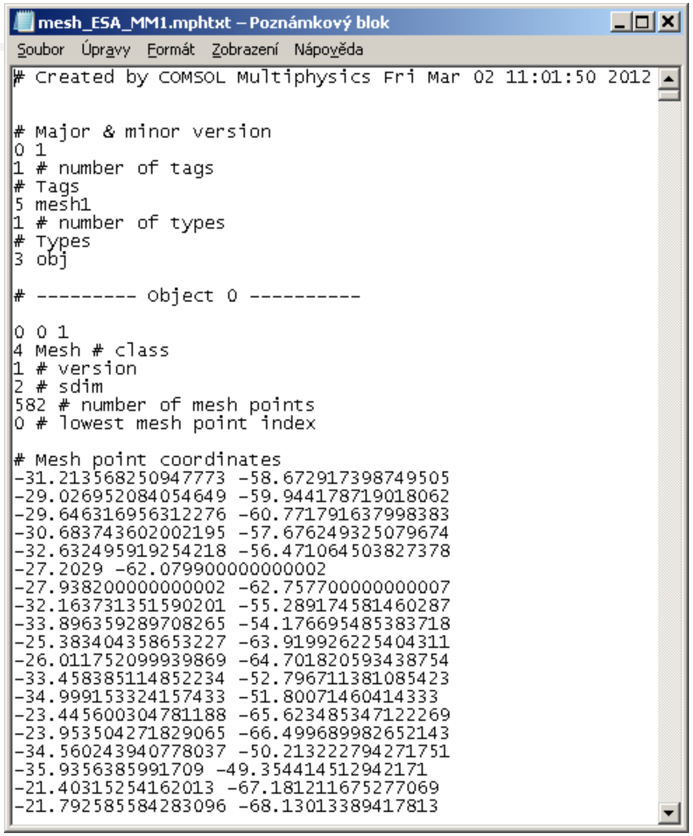
Reading binary data from file #2


mesh_ESA_MM1.mphtxt – Poznámkový blok

Soubor Úpravy Formát Zobrazení Nápověda

```
# Created by COMSOL Multiphysics Fri Mar 02 11:01:50 2012


# Major & minor version
0 1
1 # number of tags
# Tags
5 mesh1
1 # number of types
# Types
3 obj

# --------- Object 0 ----------

0 0 1
4 Mesh # class
1 # version
2 # sdim
582 # number of mesh points
0 # lowest mesh point index

# Mesh point coordinates
-31.213568250947773 -58.672917398749505
-29.026952084054649 -59.944178719018062
-29.646316956312276 -60.771791637998383
-30.683743602002195 -57.676249325079674
-32.632495919254218 -56.471064503827378
-27.2029 -62.079900000000002
-27.938200000000002 -62.757700000000007
-32.163731351590201 -55.289174581460287
-33.896359289708265 -54.176695485383718
-25.383404358653227 -63.919926225404311
-26.011752099939869 -64.701820593438754
-33.458385114852234 -52.796711381085423
-34.999153324157433 -51.800714604143333
-23.445600304781188 -65.623485347122269
-23.953504271829065 -66.499689982652143
-34.560243940778037 -50.213222794271751
-35.9356385991709 -49.354414512942171
-21.40315254162013 -67.181211675277069
-21.792585584283096 -68.13013389417813
```

```
>> size(Data)

ans =

   582     2
```

Writing to a file #1

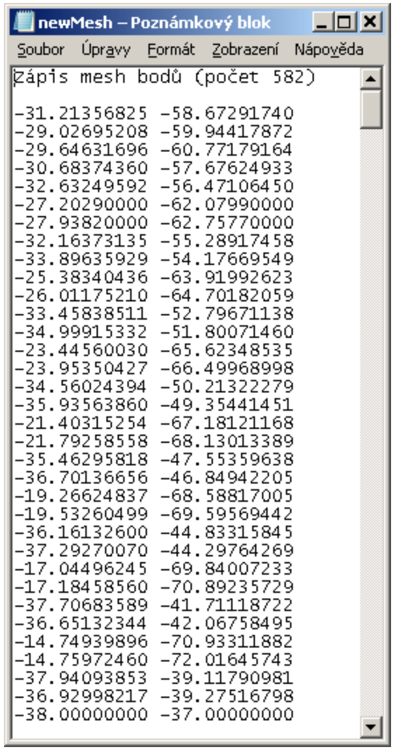
- we try to write variable `Data` from a file `data.mat` where the first line contains a header

```
>> fid = fopen('newMesh.txt');
```

```
for k = 1:size(Data,1)
    fprintf(fid, '%3.8f %3.8f\r\n', Data(k, :));
end
```

```
>> fclose(fid);
```

Writing to a file #2




```
Zápis mesh bodů (počet 582)

-31.21356825 -58.67291740
-29.02695208 -59.94417872
-29.64631696 -60.77179164
-30.68374360 -57.67624933
-32.63249592 -56.47106450
-27.20290000 -62.07990000
-27.93820000 -62.75770000
-32.16373135 -55.28917458
-33.89635929 -54.17669549
-25.38340436 -63.91992623
-26.01175210 -64.70182059
-33.45838511 -52.79671138
-34.99915332 -51.80071460
-23.44560030 -65.62348535
-23.95350427 -66.49968998
-34.56024394 -50.21322279
-35.93563860 -49.35441451
-21.40315254 -67.18121168
-21.79258558 -68.13013389
-35.46295818 -47.55359638
-36.70136656 -46.84942205
-19.26624837 -68.58817005
-19.53260499 -69.59569442
-36.16132600 -44.83315845
-37.29270070 -44.29764269
-17.04496245 -69.84007233
-17.18458560 -70.89235729
-37.70683589 -41.71118722
-36.65132344 -42.06758495
-14.74939896 -70.93311882
-14.75972460 -72.01645743
-37.94093853 -39.11790981
-36.92998217 -39.27516798
-38.00000000 -37.00000000
```

Warning message in Matlab – `warning`

- warning message in Matlab is displayed using function `warning`

```
a = 1e3;
if a > 1e2
    warning('Input coefficient has to be smaller than 10!');
end
```

  - the function is used by Matlab, therefore it is possible to temporarily deactivate selected internal warnings

- function `lastwarn` returns last warning activated

- it is advantageous to use function `warndiag` with GUI
  - but it is just a statement really, see last lecture

```
f = warndlg('This is a notice...', ...
    'Trial warning', 'modal');
```

Error message in Matlab – `error`

- error message (in red color) is displayed using function `error`

```
a = 100;
if a > 10
    error('Input has to be equal of smaller than 10!');
end
```

  - terminates program execution
  - identifier can be attached

```
error('Input has to be equal of smaller than 10!');
```

- it is advantageous to use function `warndiag` with GUI
  - but it is just a statement really, see last lecture

```
f = errordlg('An error occurred there and there...', 'Error message', 'modal');
```

Catching errors #1

- used particularly in the cases where unexpected event can occur
  - in general operations with files (reading, saving)
  - evaluation of encapsulated code (function `eval`, `assignin`)
  - working with variables, properties of which (e.g. size) is not yet known
  - evaluation of code related to an object that may not exist anymore (GUI)
  - …

```
try
    % regular piece of code
catch
    % code that is evaluated if the regular code failed
end
```

- it is possible (and is recommended) to use an identifier of the error

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Catching errors #2

- error identifier can be used to decide what to do with the error
  - example: in the case of multiplication error caused by different size of vectors, it is possible to display a warning
  - also, the error can be later raised again either by evoking the last error occurred or as a new error with its own identifier

```
try
    A = [1 1 1];
    B = [1 1];
    c = A.*B;
catch exc
    if strcmp(exc.identifier, 'MATLAB:dimagree')
        disp('Mind the vector size!');
    end
    % throw;
    % rethrow;
end
```

Time functions in Matlab

- there is a whole variety of time functions but just one of them is enough to measure time duration of a function

Function	Description
`tic - toc`	measure length of time interval between expressions `tic` and `toc`
`clock`	return six element vector `[year month day hour minute seconds]`
`date`	return date in format `dd-mmm-yyyy`, variable is of type `char` (text)
`etime`	return time interval between `t1` and `t2`, `etime(t2,t1)`
`cputime`	
`now`	return current date and time as an integer
`timeit`	measure time required to run function (new from R2013b, originally from fileexchange)

```
>> tic
>>   %% code
>> toc
```

```
>> t0 = tic;
>>   %% code
>> t1 = toc(t0)
```


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Time functions in Matlab – an example

- what is the way to measure how long it takes for a program to be executed?
  - more time consuming code × very fast code

```
tic
    % code
toc
```

```
tic
    for k = 1:100
        % code
    end
toc
```

  - other options – which one is the best?
  - Mathworks recommends functions `tic-toc` mainly for ≥P4@hyperthreading

```
t0a = tic;
fft(x);
toc(t0a)
```

```
t0b = clock;
fft(x);
etime(clock, t0b)
```

```
t0c = cputime;
fft(x);
e = cputime - t0c
```


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Time functions in Matlab – specialties

- conversions between individual ways of displaying date in Matlab
  - `datavec`, `datanum`, `datastr`
  - this is how to transform date into standard form

```
>> datevec(now)
```

- day of week:

```
>> weekday(date)
```

  - caution, US way of counting days (Saturday ~ last day of the week)

- last day of month:

```
>> eomday(2014, 1:12)
```

- calendar

```
>> calendar
```

  - caution, last day of month is Saturday again!

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Time functions in Matlab

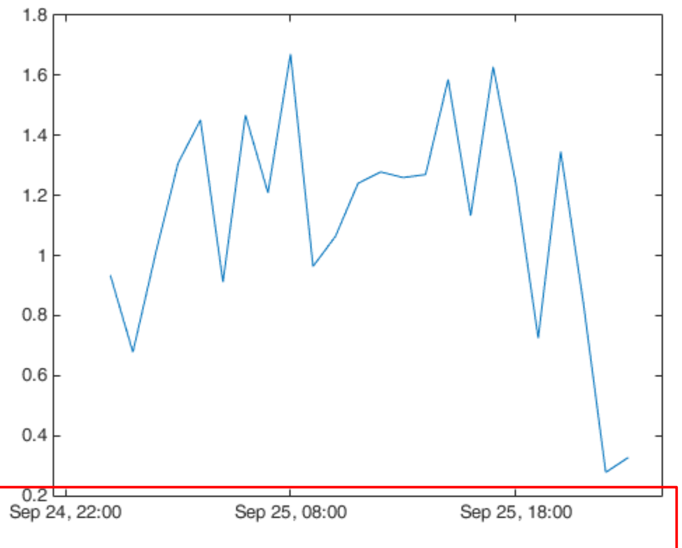
420 s

- Try to implement selected time functions into your project

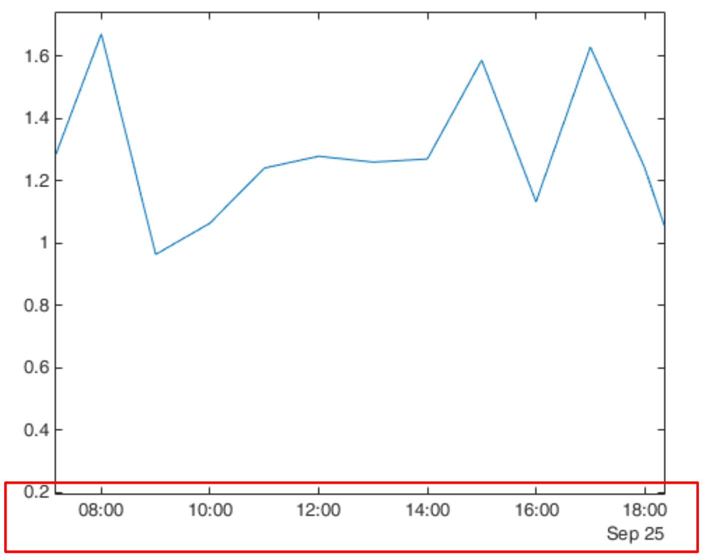
Time series data

- having data as a function of time, it is possible to display the data as a time series

```
>> d  = datetime(2015, 9, 25, 0:23, 0, 0);
>> fx = sin(linspace(0, pi, 24)) + rand(1,24);
>> plot(d, fx)
```



zoom



- for more details see:
  Matlab → Language Fundamentals → Data Types → Dates and Time

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Time data

- time entries created using `datetime` are not of class `double`, but of class `datetime`
  - it is possible to specify time zones/difference
  - all functions support vectorizing

```
>> t = datetime
>> t.Format
>> % nonsense but possible:
>> t.Format = 'd-h'
```

```
>> t1 = datetime('22/09/15 17:00:00');
>> t2 = datetime('24/12/15 19:00:00');
>> t = t1:days(7):t2
```

- it is possible to create and work with time intervals as well (class `duration`)

```
>> tInt = days(5) + hours(10)
>> 2*tInt - days(4) + 4*minutes(3)
```

'yyyy-MM-dd'	2014-04-19
'dd/MM/yyyy'	19/04/2014
'dd.MM.yyyy'	19.04.2014
'MMMM d, yyyy'	April 19, 2014
and other...	

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Class timer

- if it is desired to cyclically repeat an action, it is possible to use class `timer`
  - better possibilities compared to infinite loop
- great advantage is the fact that `timer` creates its own thread
  - it is possible to keep on working with Matlab on launching, or alternatively launch another `timer`
- example: time display + data in 1 sec interval:

```
>> tm = timer; tic; % create an instance of timer
>> tm.ExecutionMode = 'fixedRate';
>> tm.TimerFcn = 'disp(datetime); toc;';
>> start(tm); % start the timer
```

```
Elapsed time is 0.005992 seconds.
   28-Sep-2015 08:54:18

Elapsed time is 1.007364 seconds.
   28-Sep-2015 08:54:19

Elapsed time is 2.006762 seconds.
   28-Sep-2015 08:54:20

Elapsed time is 3.006012 seconds.
   28-Sep-2015 08:54:21

Elapsed time is 4.006452 seconds.
   28-Sep-2015 08:54:22

Elapsed time is 5.007007 seconds.
   28-Sep-2015 08:54:23

Elapsed time is 6.006462 seconds.
   28-Sep-2015 08:54:24

Elapsed time is 7.006668 seconds.
   28-Sep-2015 08:54:25
```

  - it is possible to keep on Working with Matlab even as `timer` is still running
  - it is not possible to terminate the thread using CTRL+C, use:

```
>> stop(tm); % stop the timer
```

- for more information see `>> doc timer`

Class `timer` – Example

```
myLine = line([0 0], [0 0]); view(45, 45); box on;
xlim([-1 1]); ylim([-1 1]); zlim([-1 1]);

thisTimer = timer;                    % create timer
thisTimer.StartDelay      = 1;    % wait 1 second
thisTimer.Period          = 0.1; % repeat action after 0.1s
thisTimer.ExecutionMode   = 'fixedSpacing'; % spacing
thisTimer.UserData        = 0;    % data which we need...
thisTimer.TimerFcn        = {@timer_update, myLine, pi/16};
start(thisTimer);                     % start the timer...

fghndl = gcf;                % stop timer if the figure is closed
fghndl.CloseRequestFcn = 'stop(thisTimer); closereq;';
```

```
function timer_update(myTimer, ~, myLine, dPhi)

myLine.XData = [1 -1]*sin(myTimer.UserData);
myLine.YData = [1 -1]*cos(myTimer.UserData);
drawnow('update');        % update graphics

myTimer.UserData = myTimer.UserData + dPhi;
```

Layout of your own instance of `timer`

420 s ↑

- Create a timer that displays, with 0.5 sec interval, "*XX* | *Hello world.*", where *XX* is the order of the message being displayed. Timer will be terminated after reaching 15 displays.

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Higher math

- two different attitudes are distinguished
  - symbolic math
  - numeric math
    - numerical errors
  - possible classification: analytical result in principle enables to get result in infinite number of decimals
- there exist wide range of techniques in Matlab (symbolical as well as numerical)
  - only selected techniques will be covered

Handle functions – revision

- enables indirect function invoking
- reference to the function is stored in `handle`

```
handle1 = @function_name
handle2 = @(args) function_name
```

- it is quite powerful tool though a bit more complicated
  - enables to invoke a function from locations where it is not visible to Matlab
  - function handle is a data type in Matlab (see `whos`)

```
>> clear,clc;
>> doc function_handle

>> fxy = @(x, y) x^2 + y^2 - 5
>> fxy(2, -2)

>> fcos = @(alpha) cos(alpha)
>> fcos(pi)
```

Polynomials #1

- representation of polynomials in Matlab

$$\mathrm{P} = C_n x^n + C_{n-1} x^{x-1} + \ldots + C_1 x + C_0 = \begin{bmatrix} C_n & C_{n-1} & \ldots & C_1 & C_0 \end{bmatrix}$$

```
>> x = roots([1 0 -1]);
>> x1 = x(1)
>> x2 = x(2)
```

- function `roots` finds roots of a polynomial
- polynomial evaluation: `polyval`

```
>> x = 2
>> p1 = 3*x^5 - 7*x^3 + 1/2*x^2 - 5
>> polyval([3 0 -7 1/2 0 -5], 2)
```

- polynomial multiplication: `conv`

$$\mathrm{A}_1 = x - 1$$

$$\mathrm{A}_2 = x + 1$$

$$\mathrm{A}_1 \cdot \mathrm{A}_2 = (x-1) \cdot (x+1) = x^2 - 1$$

```
>> A1 = [1 -1]
>> A2 = [1 1]
>> conv(A1, A2)
% = [1 0 -1]
```


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Polynomials #2

- polynomial division: `deconv`

```
>> deconv([1 0 -1], [1 1]) % = [1 -1]
```

$$\frac{x^2-1}{x+1}=\frac{(x-1)\cdot(x+1)}{x+1}=x-1$$

- other polynomial related functions (selection of some):
  - `residue`: residue of ratio of two polynomials
  - `polyfit`: approximation of data with polynomial of order `n`
  - `polyint`: polynomial integration
  - `polyder`: polynomial derivative

```
>> S = [1 1];
>> T = polyint(S) % = [0.5 1 0]
>> U = polyder(T) % = S = [1 1]
>> polyder(U)     % = 1
```

$$\int (x+1)\mathrm{d}x=\frac{1}{2}x^2+x$$

$$\frac{\mathrm{d}\left(\frac{1}{2}x^2+x\right)}{\mathrm{d}x}=x+1$$

Polynomials #3

- polynomial multiplication

$$P1 = A + Bx \qquad P2 = 4x^2 + 2x - 4$$

```
>> syms A B x
>> P1 = A + B*x;           % entering 1. polynomial
>> P2 = 4*x^2 + 2*x - 4;   % 2. polynomial
>> P0 = P1*P2;             % multiplication
>> P  = expand(P0)         % expansion
```

- note: function `expand` requires Symbolic Math Toolbox

x = ?: f(x) == g(x)

- two functions are given, we want to analytically find out points where these functions are equal to each other

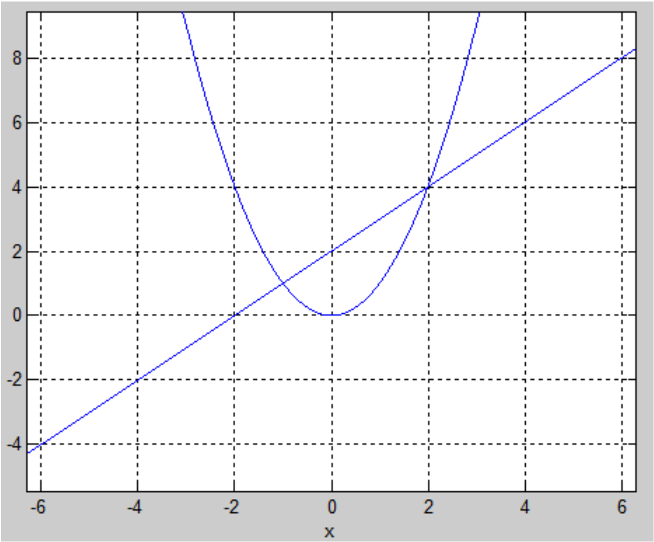
$f(x) = x^2$ $\qquad g(x) = x + 2$ $\qquad x = ?:\{f(x) = g(x)\}$

enter

```
>> clear,clc;
>> syms x;
>> f = x^2;
>> g = x + 2;
```

solve

```
>> x0 = solve(f - g) % = 2; -1
```



check

```
>> ezplot(f);
>> hold on;
>> grid on;
>> ezplot(g);
```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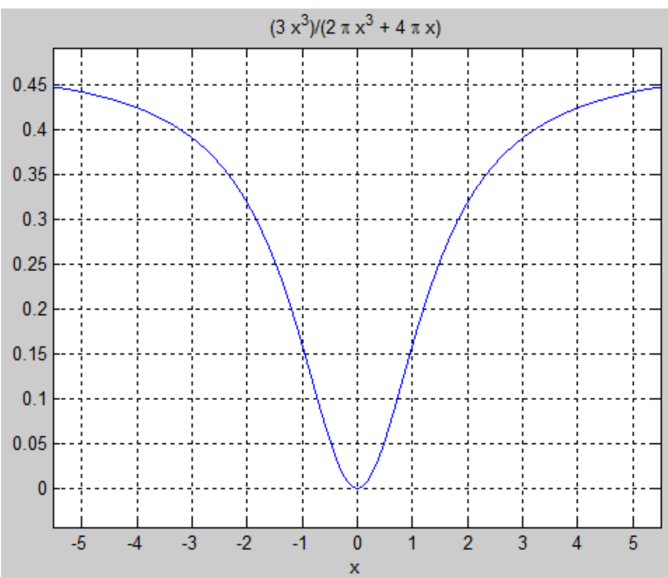
Function limit

- find out function limit

$$f(x) = \frac{3x^3}{2\pi x^3 + 4\pi x} \qquad f(x) = \frac{3}{2\pi}\left(\frac{x^2}{x^2+2}\right) \qquad \lim_{x\to-\infty} f(x) = \lim_{x\to\infty} f(x) \overset{L'H.P.}{=} \frac{3}{2\pi} = 0.4775$$

enter

```
>> clear, clc, close all;
>> syms x real;
>> f = 3*x^3/(2*pi*x^3 + 4*pi*x)
```



solve

```
>> lim1 = limit(f, x, -inf)
>> lim2 = limit(f, x, inf)

>> double(lim1) % = 0.4775
>> double(lim2) % = 0.4775
```

check

```
>> figure;
>> ezplot(f);
>> grid on;
```

Function derivative #1

- apply L'Hospital's rule to previous function
  - function $f(x)$ contains 3rd power of x; carry out 3rd derivative (of numerator and denominator separately) in x

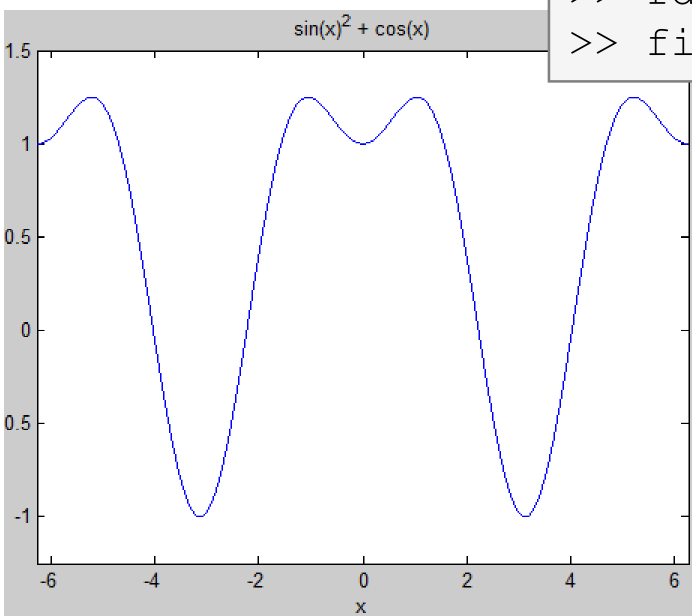
$$f(x)=\frac{3x^3}{2\pi x^3+4\pi x} \qquad f_1(x)=3x^3 \qquad f_2(x)=2\pi x^3+4\pi x$$

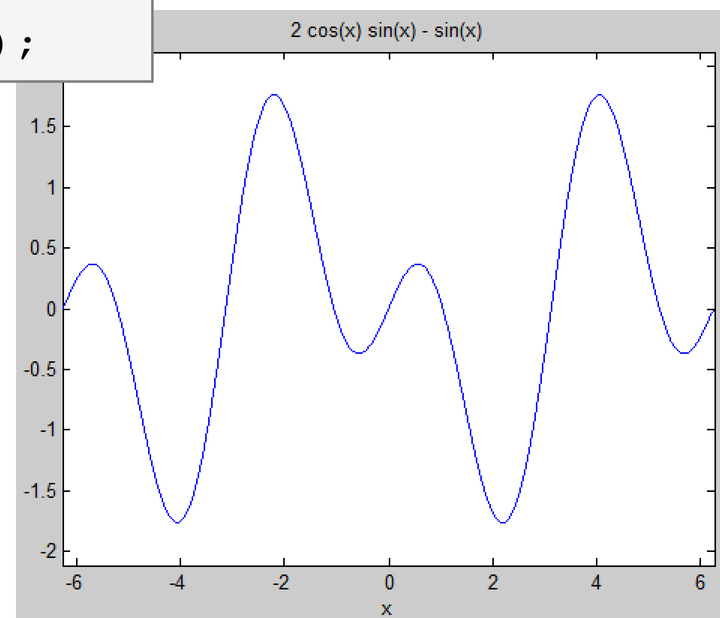
```
>> f1 = 3*x^3;
>> f2 = 2*pi*x^3 + 4*pi*x;
>> A1 = diff(f1,3)
>> A2 = diff(f2,3)
>> double(A1/A2) % = 0.4775
```

Function derivative #2

- carry out derivative of the following function in x $f(x) = \sin^2(x) + \cos(x)$
  - compare results and plot them

```
>> clear, clc;
>> syms x;
>> f = sin(x)^2 + cos(x);
>> figure; ezplot(f);
>> fd = diff(f);
>> figure; ezplot(fd);
```





Integration #1

- let's first symbolically carry out derivative of function $f(x) = \sin(x) + 2$
- save the second derivative of *f* and call it *g*, compare results
- now integrate function *g* (1×, 2×), do we get the original function *f* ?
  - ignore integration constants

```
>> clear, clc;
>> x = sym('x');

>> f = sin(x) + 2
>> figure; ezplot(f);

>> fd = diff(f)
>> figure; ezplot(fd);

>> fdd = diff(f, 2)
>> figure; ezplot(fdd);
```

```
>> g = fdd;
>> gi = int(g)
>> figure; ezplot(gi);

>> gii = int(gi);
>> err = f - gii

figure;
subplot(1, 2, 1);
ezplot(f);
subplot(1, 2, 2);
ezplot(gii);
```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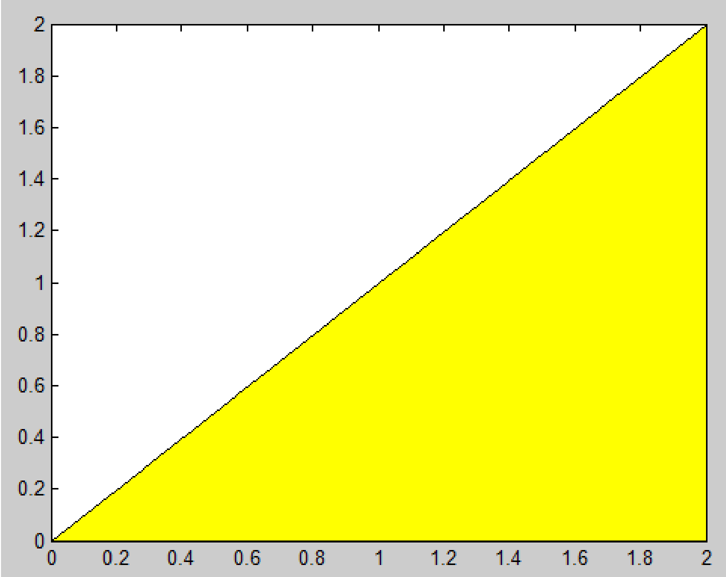
Integration #2

- integral of a function $f(x) = x$
  - calculate following integral $I = \int_0^2 f(x)\,\mathrm{d}x$
  - do the calculation manually, plot the function
  - calculate indefinite integral in Matlab
  - calculate definite integral on interval (0, 2), use e.g. function `int`

$$I = \int_0^2 f(x)\,\mathrm{d}x = \int_0^2 x\,\mathrm{d}x = \left[\frac{x^2}{2}\right]_0^2 = \frac{4}{2} - 0 = 2$$

$$I = \frac{2 \cdot 2}{2} = 2$$

```
>> fill([0 2 2], [0 0 2], 'y')
```



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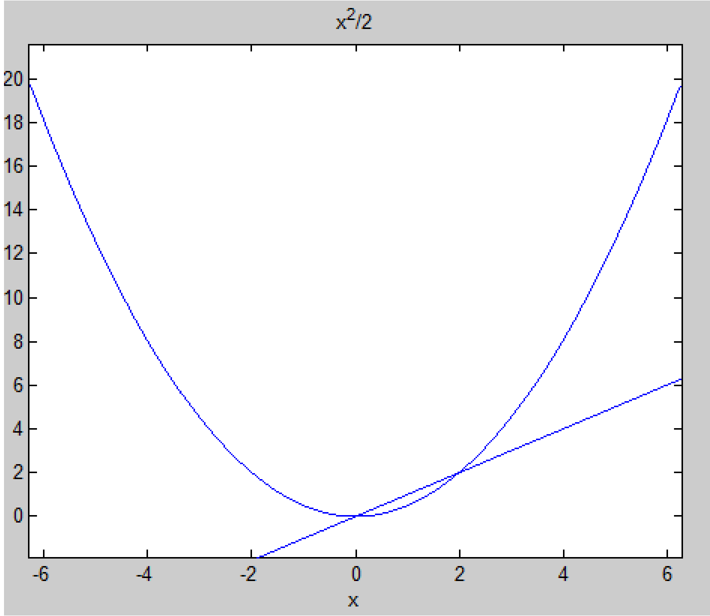
Integration #3

- integral of a function




```
>> clear, clc;
>> syms x;
>> f = x;
>> g = int(x);

>> figure;
>> ezplot(f);
>> hold on;
>> ezplot(g);

>> int(f, x, 0, 2)                % = 2
>> polyarea([0 2 2], [0 0 2]) % = 2

% BUT!:
>> f = @(x) x  % function_handle!
>> I = quad(f, 0, 2)              % = 2
```

Numerical integration #1

- numerical approach is used whenever the closed-form (analytical) solution is not known which happens quite often in technical sciences (almost always)

- it is possible to use various numerical integration methods, see literature
- alternatively, Matlab functions can be utilized
  - `quad`, `dblquad`, `triplequad` and others
    - `integral`, `integral2`, `integral3` functions in new versions of Matlab
  - define function to be integrated (write your own function or use *function handle*)

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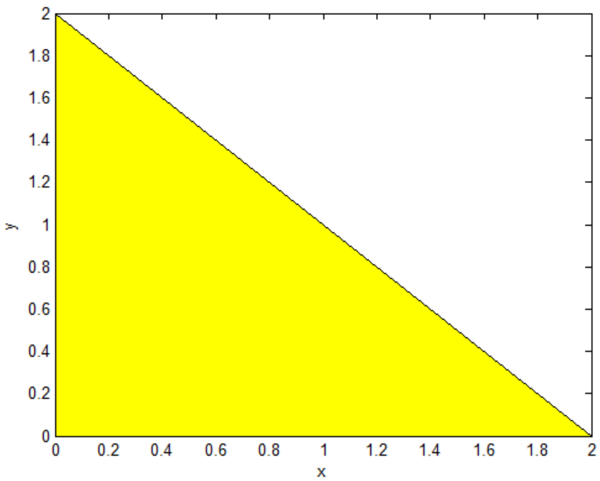
Numerical integration #2

- solve the following integral on the interval

$$x \in (0,2),$$
$$y \geq 0 \wedge y \leq 2 - x$$

$$I = \iint_S f(x,y)\mathrm{d}S \qquad f(x,y) = x + y$$



$$I = \int_0^2 \int_0^{y_{\max}} f(x,y)\mathrm{d}x\mathrm{d}y = \int_0^2 \int_0^{2-x} (\mathrm{x}+\mathrm{y})\mathrm{d}x\mathrm{d}y = \int_0^2 \left(x\left[\mathrm{y}\right]_0^{2\text{-x}} + \left[\frac{y^2}{2}\right]_0^{2\text{-x}} \right)\mathrm{d}x$$

$$= \int_0^2 \left(x(2-x) + \frac{(2-x)^2}{2} \right)\mathrm{d}x = \int_0^2 \left(2x - x^2 + 2 - 2x + \frac{x^2}{2} \right)\mathrm{d}x$$

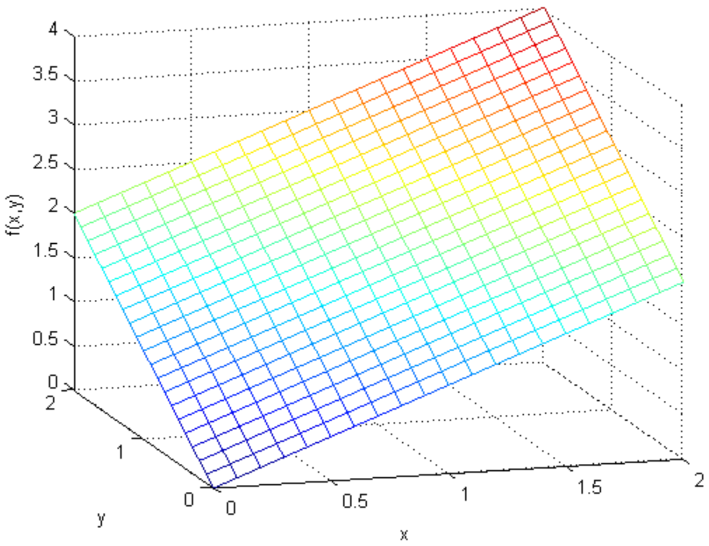
$$= \int_0^2 \left(2 - \frac{x^2}{2} \right)\mathrm{d}x = 2\left[x\right]_0^2 - \frac{1}{2}\left[\frac{x^3}{3}\right]_0^2 = 4 - 8\cdot\frac{1}{6} = \frac{12-4}{3} = \frac{8}{3} = 2.\overline{666}$$

Numerical integration #3

- solve the following integral on the interval

$$x \in (0,2),$$
$$y \geq 0 \wedge y \leq 2 - x$$

$$I = \iint_S f(x, y)\mathrm{d}S \qquad f(x, y) = x + y$$



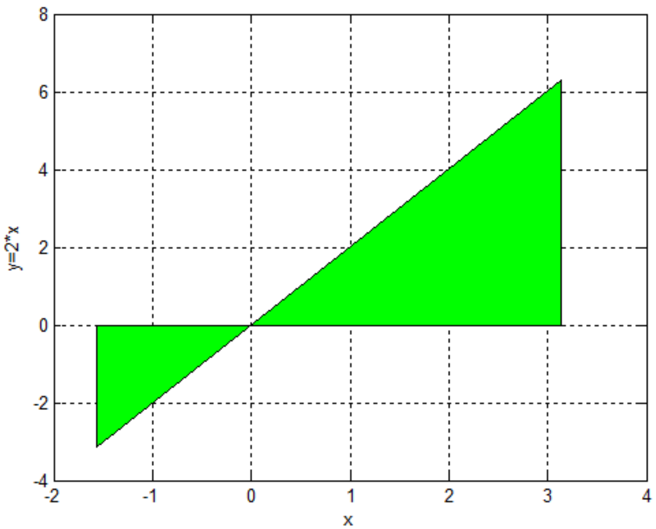

```
>> clear, clc;
% solution:
>> f = @(x, y) x + y
>> ymax = @(x) 2 - x
>> integral2(f, 0, 2, 0, ymax)

% plotting
>> t = 0:1/10:2
>> [x, y] = meshgrid(t);
>> z = x + y;
>> figure('color', 'w');
>> mesh(x, y, z);
```

Numerical integration #4

- it is possible to work with external scripts as well; i.e. having „complex“ expression that we don’t want to process as handle:

$$I=\int_x f(x)\mathrm{d}x=\int_{-\frac{\pi}{2}}^{\pi}2x\mathrm{d}x=2\int_{-\frac{\pi}{2}}^{\pi}x\mathrm{d}x=2\left[\frac{x^2}{2}\right]_{-\frac{\pi}{2}}^{\pi}=\pi^2-\frac{\pi^2}{4}=\underline{\underline{\frac{3}{4}\pi^2}}$$




```
function fx = myIntFcn(x)
% function to calculate integral:
% int{2*x}

c  = 2;
fx = c*x;
```

```
>> quad(@myIntFcn, -pi/2, pi)
```

Numerical integration #1

- general problem of derivative (it is not possible to approach zero)

$$\lim_{\Delta x \to 0} \frac{f(x+\Delta x) - f(x)}{\Delta x}$$

- various sophisticated numerical methods of various complexity are used

- web pages to solve this problem in a complex way :
  - `http://www.matrixlab-examples.com/derivative.html`

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

Closing notes

- in the case there is a lot of symbolic calculations or when approaching Matlab limits, try another mathematical tool (for analytical solution especially Maple, Mathematica)

- nevertheless Matlab is a perfect choice for numerical computing (although both Mathematica's symbolic and numerical kernels are excellent)

Higher math

- polynomials
  - http://www.matrixlab-examples.com/polynomials.html
- single and double integration (symbolic)
  - http://www.matrixlab-examples.com/definite-integrals.html
- derivative (numerical)
  - analytic input:
    - http://www.matrixlab-examples.com/derivative.html
  - numeric input
    - manual derivative

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

Summary of `is*` functions

- asterisk stands for whole range of functions
  - return value is logical (`true` / `false`)
- selection of the interesting ones (some even have multiple parameters)

Function	Description
`ischar`	determine whether item is character array
`isempty`	determine whether array is empty
`isfinite`	determine whether elements are of finite size
`isnan`	determine whether elements are `NaN`
`isletter`	determine whether elements are alphabetical letters (a-z, A-Z)
`islogical`	determine whether input is logical array
`isnumeric`	determine whether elements are numeric values (real, complex scalars, matrices, vectors,integers)
`isreal`	determine whether input is real array
`isstudent`	determine whether Matlabu version is Student Version?
and others	see `>> doc is*`

Function `is*`

420 s

- try following examples
  - consider in what situation they could prove useful…

```
>> A = 'pi5_7';
>> B = pi;
>> C = [Inf NaN 5.31 true false pi];
>> D = [[] []];
>> ischar(A), ischar(B),
>> isstudent, isunix, computer,
>> isnan(A)
>> isnan(C)
>> ischar(A), ischar(B),
>> isempty(C), isempty(D),
>> isfinite(A), isfinite(C),
>> isletter(A),
>> islogical(C), islogical([true false]),
>> isnumeric(A), isnumeric(C)
```


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

Discussed functions

`tic, toc, clock, date, etime, cputime, now`	time functions, measurement of code speed	
`datevec, weekday, eomday, calendar`	time functions (days in week, month, callendat)	
`warning, error, try-catch`	warning, error message, error catching	●
`throw, rethrow`	exception issue	●
`cell, celldisp, cellplot`	variable `cell` (allocation, display)	
`setfield, fieldnames, getfield, rmfield`	structure-related functions	
`isfield, isstruct`	input is array field?, input is `struct`?	
`uiimport`	Matlab import Wizard	●
`xlsread, xlswrite`	read/write Excel spreadsheet	●
`fopen, feof, fclose, fgetl`	file open, test for end-of-file, file close, read line from file	●
`sym, syms`	create symbolic variable(s)	
`roots, polyval, conv, deconv`	polynomial-related functions 1	
`residue, polyfit, polyder, polyint, expand`	polynomial-related functions 2	
`solve`	equations and systems solver	●
`limit, diff, int`	function limit, derivative, function integration	
`ezplot`	symbolic function plotter	
`quad (integral), quad2d (integral2)`	numeric integration	●

Thank you!

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

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