

Matlab and Programming

Programming basics and algorithms

Ivo Roghair, Martin van Sint Annaland

Chemical Process Intensification
Eindhoven University of Technology

Part I

Matlab introduction

Today's outline

① Introduction

② Data structures

③ Plotting

④ Creating algorithms

⑤ Functions

Programming

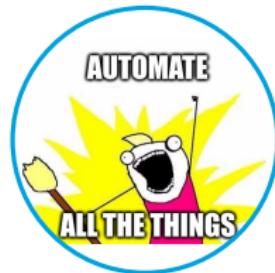
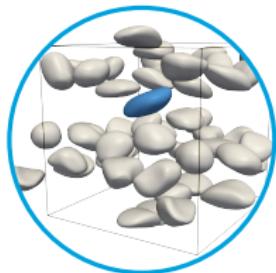
“Everybody in this country should learn to program a computer, because it teaches you to think..”

—Steve Jobs



Why?

- Scientific techniques depend in an increasing fashion upon computer programs and simulation methods
- Knowledge of programming allows you to automate routine tasks
- Ability to understand algorithms by inspection of the code
- Learn to think by dissecting a problem into smaller bits



Getting started

Start Matlab, and enter the following commands on the command line. Evaluate the output.

```
>> 2 + 3 % Some simple calculations
>> 2*3
>> 2*3^2 % Powers are done with ^
>> a = 2 % Storing values into the workspace
>> b = 3
>> c = (2*3)^2 % Parentheses set priority
>> 8/a-b
>> sin(a) % Mathematical functions can be used
>> sin(0.5*pi) % pi is an internal Matlab variable
>> 1/0 % Infinity is a thing ...
>> sqrt(-1) % ... as are imaginary numbers
```

Introduction to programming

What is a program?

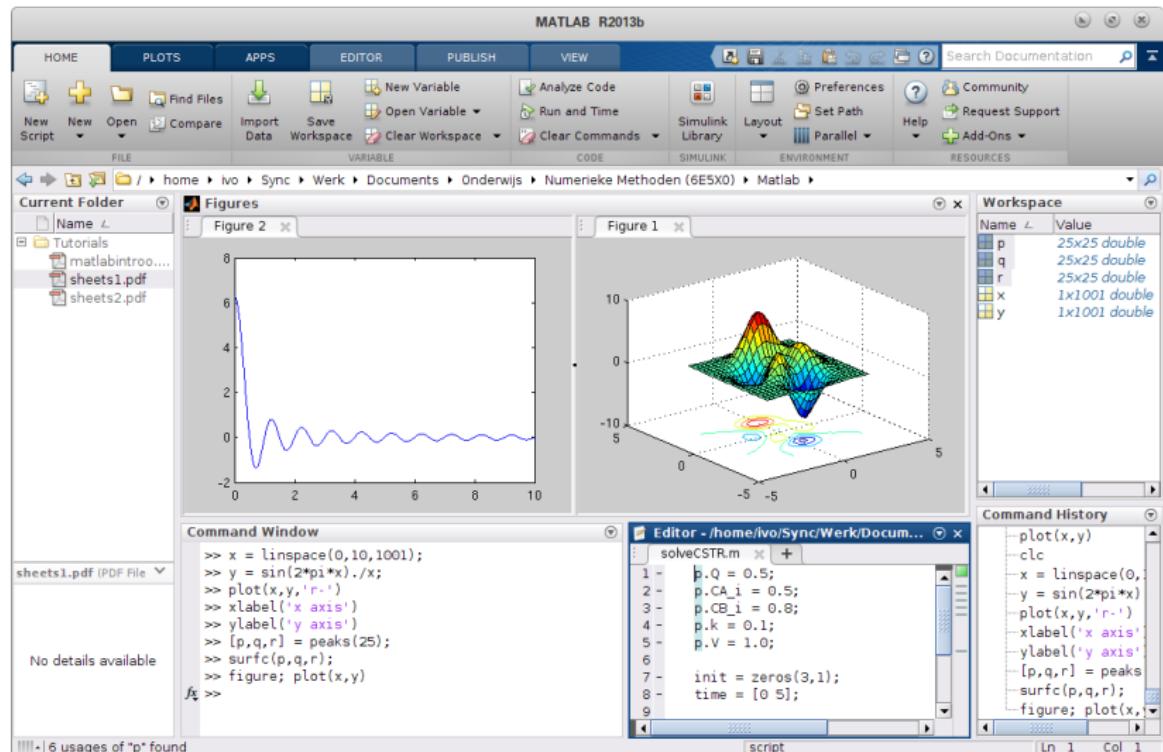
A program is a sequence of instructions that is written to perform a certain task on a computer.

- The computation might be something mathematical, a symbolic operation, image analysis, etc.

Program layout

- ① Input (Get the radius of a circle)
- ② Operations (Compute and store the area of the circle)
- ③ Output (Print the area to the screen)

Versatility of Matlab

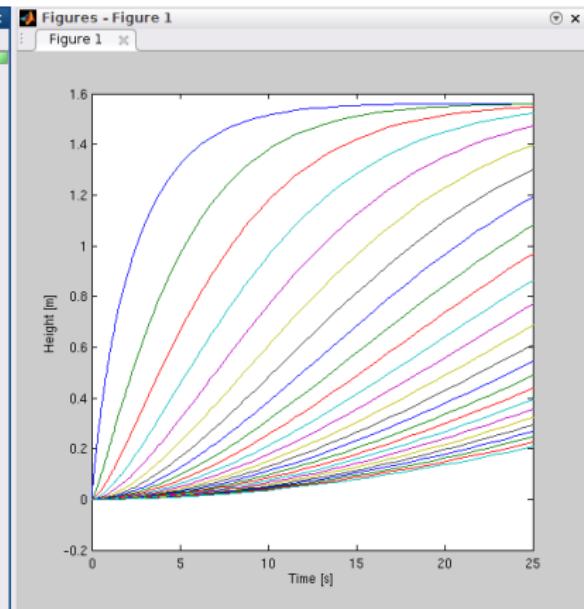


Versatility of Matlab: ODE solver

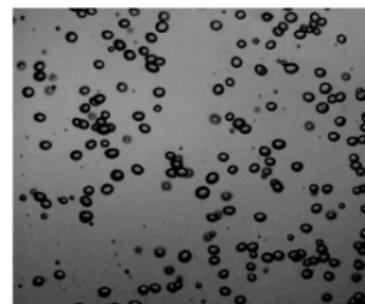
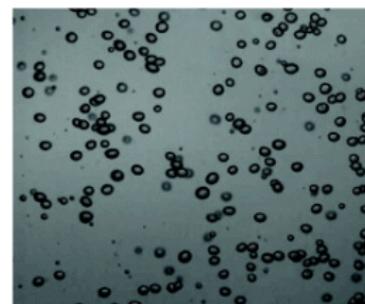
Editor - /mnt/data/BittorrentSync/Werk/Documents/Onderwijs/Pra... × x

solveTankSeries.m tankSeries.m +

```
1 - p.F0 = 1.0;
2 - p.K = 0.8;
3 - p.N = 25;
4 - p.A = 1.0;
5 -
6 - init = zeros(p.N,1);
7 - time = [0 25];
8 -
9 - [t,h] = ode45(@tankSeries,time,init,[],p);
10
11 - plot(t,h);
12 - xlabel('Time [s]');
13 - ylabel('Height [m]');
```

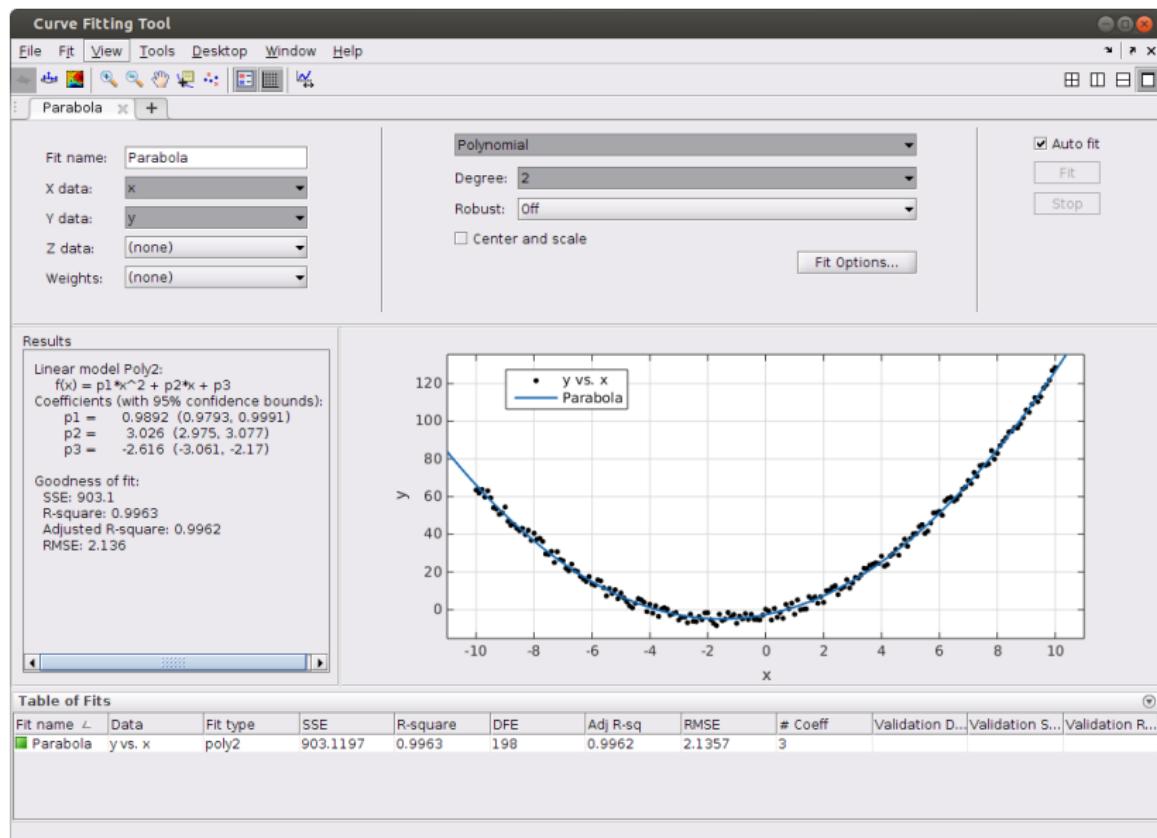


Versatility of Matlab: Image analysis



```
I = imread('bubbles.png');  
BW = rgb2gray(I);  
E = edge(BW, 'canny');
```

Versatility of Matlab: Curve fitting



Matlab help

- Matlab documentation: `doc` or `help` function
- Canvas page
- Introduction to Numerical Methods and Matlab Programming for Engineers. T. Young and M.J. Mohlenkamp (2015). GNU-licensed document, online
- Search the web!



Today's outline

① Introduction

② Data structures

③ Plotting

④ Creating algorithms

⑤ Functions

Terminology

Variable Piece of data stored in the computer memory, to be referenced and/or manipulated

Function Piece of code that performs a certain operation/sequence of operations on given input

Operators Mathematical operators (e.g. + - * or /), relational (e.g. < >or ==, and logical operators (&&, ||)

Script Piece of code that performs a certain sequence of operations without specified input/output

Expression A command that combines variables, functions, operators and/or values to produce a result.

Variables in Matlab

- Matlab stores variables in the *workspace*
- You should recognize the difference between the *identifier* of a variable (its name, e.g. `x`, `setpoint_p`), and the data that it actually stores (e.g. 0.5)
- Matlab also defines a number of variables by default, e.g. `eps`, `pi` or `i`.
- You can assign a variable by the = sign:

```
>> x = 4*3
x =
    12
```

- If you don't assign a variable, it will be stored in `ans`
- Clearing the workspace is done with `clear`.

Datatypes and variables

Matlab uses different types of variables:

Datatype	Example
string	'Wednesday'
integer	15
float	0.15
vector	[0.0; 0.1; 0.2]
matrix	[0.0 0.1 0.2; 0.3 0.4 0.5]
struct	sct.name = 'MyDataName' sct.number = 13
logical	0 (false) 1 (true)

About variables

- Matlab variables can change their type as the program proceeds (this is not common for other programming languages!):

```
>> s = 'This is a string'  
s =  
This is a string  
>> s = 10  
s =  
10
```

- Vectors and matrices are essentially *arrays* of another data type. A vector of `struct` is therefore possible.
- Variables are *local* to a function (more on this later).

Vectors in Matlab (1)

A row vector:

```
>> v = [0 1 2 3]
```

A column vector by separating elements with semi-colons:

```
>> u = [9; 10; 11; 12; 13; 14; 15]
```

Access (i.e. read) an entry in a vector:

```
>> u(2)
```

Manipulate the value of that entry:

```
>> u(2)=47
```

Get a slice of a vector:

```
>> u([2 3 4]) % With colon operator: u(2:4)
```

Transposing vectors:

```
>> w = v'
```

Vectors in Matlab (2)

Manual definition may be cumbersome. A colon (:) generates a list:

```
>> a = 1:10      % Default stride is 1
>> x = -1:.1:1    % start:stride:stop specifies list
```

Or, when you prefer to set the *number of elements* instead of the step size:

```
>> y = linspace(0,10,11)
>> p = logspace(2,6,5)
```

Manipulating multiple components:

```
>> y([1 4:7]) = 1
```

Or (by supplying a vector instead of a scalar):

```
>> y([1 4:7]) = 16:20 % equivalent to y([1 4 5 6 7]) =
[16 17 18 19 20]
```

Practice

Given a vector

$$x = [2 \ 4 \ 6 \ 8 \ 10 \ 12 \ 14 \ 16 \ 18 \ 20 \ 30 \ 40 \ 50 \ 60 \ 70 \ 80]$$

- Find a way to define the vector without typing all individual elements
- Investigate the meaning of the following commands:

```
>> y = x(5:end)  
>> y(4)  
>> y(4) = []  
>> sum(x)  
>> mean(x)  
>> std(x)  
>> max(x)  
>> fliplr(x)  
>> diff(x)
```

Operations on vectors (1)

```
>> e = 1:5  
>> f = 2*e  
>> g = 4*f + 20  
>> h = e^2
```

... wait ... what's that?

```
Error using ^  
Inputs must be a scalar and a square matrix.  
To compute elementwise POWER, use POWER (.^) instead.
```

Matlab uses matrix operations by default, we should use a dot operator to make operations element-wise for *, / and ^.

```
>> e.^2
```

Operations on vectors (2)

To demonstrate the matrix product:

```
>> p = [1; 1; 1]
>> q = [1 2 3]
>> p*q    % which is not equal to q*p
```

All kinds of mathematical functions on vectors typically operate on elements:

```
>> x = linspace(0,2*pi,100);
>> s = sin(x)
>> e = exp(x)
```

Building blocks: Mathematics and number manipulation

Programming languages usually support the use of various mathematical functions (sometimes via a specialized library). Some examples of the most elementary functions in Matlab:

Command	Explanation
<code>cos(x)</code> , <code>sin(x)</code> , <code>tan(x)</code>	Cosine, sine or tangens of x
<code>mean(x)</code> , <code>std(x)</code>	Mean, st. deviation of vector x
<code>exp(x)</code>	Value of the exponential function e^x
<code>log10(x)</code> , <code>log(x)</code>	Base-10/Natural logarithm of x
<code>floor(x)</code>	Largest integer smaller than x
<code>ceil(x)</code>	Smallest integer that exceeds x
<code>abs(x)</code>	Absolute value of x
<code>size(x)</code>	Size of a vector x
<code>length(x)</code>	Number of elements in a vector x
<code>rem(x,y)</code>	Remainder of division of x by y

Printing results

You can prevent displaying the outcome of a command by adding a semi-colon at the end of a line:

```
>> c = linspace(0,10,11);  
>> length(c)  
>> c  
>> size(c)
```

Altering the display format can be done using the `format` command:

```
>> format compact % loose  
>> format long % short
```

Simple plotting

Make a plot of the following table

T (°C)	5	20	30	50	55
μ (Pa·s)	0.08	0.015	0.009	0.006	0.0055

```
>> T = [ 5 20 30 50 55 ]  
>> mu = [ 0.08 0.015 0.009 0.006 0.0055]
```

```
>> plot(T,mu)
```

```
>> plot(T,mu,'*')
```

```
>> plot(T,mu,'r--')
```

```
>> plot(T,mu,'ko-', 'LineWidth',2)
```

```
>> xlabel('Temperature [^\circ C]')  
>> ylabel('Viscosity [Pa s]')  
>> title('Experiment 1')
```

Practice

Create plots of the following functions in a single figure for $x \in \{0, 2\pi\}$:

$$y_1 = \cos x$$

$$y_2 = \arctan x$$

$$y_3 = \frac{\sin x}{x}$$

Strategies to draw multiple graphs in 1 figure:

```
>> plot(x,y1,x,y2,x,y3)
```

```
>> plot(x,y1)
>> hold on; % Maintain drawn plots in current figure
>> plot(x,y2)
>> plot(x,y3) % The 'hold-property' was already set
```

Matrices in Matlab

Matrix A is defined as:

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

In Matlab:

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

Elements can be accessed/manipulated by the following syntax:

```
>> A(3,1) % Third row, first column, also A(3)
>> A(3,:) = [2 4 8] % Set entire third row
>> A(:,3) % Print third column
>> A(A>5) = 2 % Set elements by condition
```

There are a few functions that help creating matrices:

```
>> A = zeros(4) % A 4x4 matrix with zeros
>> A = ones(4,1) % A 4-element vector with ones
>> A = eye(3) % Identity matrix of 3x3
>> A = rand(3,4) % A 3x4 matrix with random numbers
```

Practice

- Find a *short* Matlab expression to create the following matrix:

$$A = \begin{bmatrix} 1 & 2 & 3 & 4 & 5 & 6 & 7 \\ 9 & 7 & 5 & 3 & 1 & -1 & -3 \\ 4 & 8 & 16 & 32 & 64 & 128 & 256 \end{bmatrix}$$

- Investigate the command `max(A)`. What does it give?

Today's outline

① Introduction

② Data structures

③ Plotting

④ Creating algorithms

⑤ Functions

Building blocks: conditional statements

if-statement: Check whether a (set of) condition(s) is met.

```
num = floor (10 * rand + 1);
guess = input ('Your guess please : ');
if ( guess ~= num )
    disp (['Wrong, it was ',num2str(num),'. Kbye.']);
else
    disp ('Correct !');
end
```

Other relational operators

==	is equal to
<=	is less than or equal to
>=	is greater than or equal to
<	is less than
>	is greater than

Combining conditional statements

&&	and
 	or
xor	exclusive or

Building blocks: loops

for-loop: Performs a block of code a certain number of times.

```
>> p(1) = 1;
>> p(2) = 1;
>> for i = 2:10
p(i+1) = p(i)+p(i-1);
end
>> p
p =
    1     1     2     3     5     8    13    21    34    55    89
```

Building blocks: indeterminate repetition

`while`-loop: Performs and repeats a block of code until a certain condition.

```
num = floor (10* rand +1) ;
guess = input ('Your guess please : ');

while ( guess ~= num )
    guess = input ('That is wrong. Try again ... ');
end

if (isempty(guess))
    disp('No number supplied - exit');
else
    disp ('Correct!');
end
```

Example algorithm

Compute the factorial of N : $N! = N \cdot (N - 1) \cdot (N - 2) \cdots 2 \cdot 1$

How to deal with this?

Naive approach

```
Z = 1;  
Z = Z*2;  
Z = Z*3;  
Z = Z*4;  
... etc ...
```

For-loop

```
Z = 1;  
for i = 1:N  
    Z = Z*i;  
end
```

While-loop

```
Z = 1;  
i = 1;  
while (i<=N)  
    Z = Z*i;  
    i = i+1;  
end
```

Note: N must be set beforehand!

Note: Pay attention to the relational operators!

Building blocks: case selection

switch-statement: Selects and runs a block of code.

```
[dnum,dnam] = weekday(now);
switch dnum
    case {1,7}
        disp('Yay! It is weekend!');
    case 6
        disp('Hooray! It is Friday!');
    case {2,3,4,5}
        disp(['Today is ', dnam]);
    otherwise
        disp('Today is not a good day...');

end
```

Input and output

Many programs require some input to function correctly. A combination of the following is common:

- Input may be given in a parameters file (“hard-coded”)
- Input may be entered via the keyboard

```
>> a = input('Please enter the number ');
```

- Input may be read from a file, e.g.

```
>> data = getfield(importdata('myData.txt', ' ',  
    4), 'data');  
>> numdata = xlsread('myExcelDataFile.xls');
```

- There are many more advanced functions, e.g. `fread`, `fgets`, ...

Input and output

Output of results to screen, storing arrays to a file or exporting a graphic are the most common ways of getting data out of Matlab:

- Results of each expression are automatically shown on screen as long as the line is not ended with a semi-colon;
- Output may be stored via the GUI:
 - Use the 'Export Setup' function
 - Save figure (use .fig, .eps or .png, not .jpg or .pcx)
 - Save variables (right click, save as)
- Save variables automatically (scripted):

```
>> savefile = 'test.mat';
>> p = rand(1,10);
>> q = ones(10);
>> save(savefile, 'p', 'q')
```

- More advanced functions can be found in e.g. `fwrite`, `fprintf`,
...

Today's outline

① Introduction

② Data structures

③ Plotting

④ Creating algorithms

⑤ Functions

Functions - general

A function in a programming language is a program fragment that performs a certain task. Creating functions keeps your code clean, re-usable and structured.

- You can use functions supplied by the programming language, and define functions yourself
- Functions take one or more input parameters (*arguments*), and *return* an output (*result*).
 - If functions do not return a result, it is called a procedure
- In Matlab, functions are defined as follows (2 output variables and 3 input arguments):

```
function [out1, out2] = myFunction(in1, in2, in3)
```

Functions - locality and arguments

- You are supplying arguments to a function because it does not have access to previously defined variables. This is called *locality*.
 - This does not include global variables - but they're evil!
 - Local variables created in a function are not accessible to other functions unless they are returned or supplied as an argument!

Example: write a function that takes 3 variables, and returns the average:

Approach 1

```
function res = avg1(a,b,c)
    mySum = a + b + c;
    res = mySum / 3;
end
```

Approach 2

```
function res = avg2(a,b,c)
    data = [a; b; c];
    res = mean(data);
end
```

Exercise: create a function

Compute $N! = N \cdot (N - 1) \cdot (N - 2) \cdots 2 \cdot 1$

Create a function of our while-loop approach with N the argument:

Original script

```
Z = 1;  
i = 1;  
while (i<=N)  
    Z = Z*i;  
    i = i+1;  
end
```

Function

```
function Z = fact_while(N)  
  
Z = 1;  
i = 1;  
while (i<=N)  
    Z = Z*i;  
    i = i+1;  
end  
  
end
```

Functions - checking input

The function we created computes the factorial correctly!

- When the supplied argument is positive and
- When the supplied argument is a natural number...



- In this case, we should check the user input to prevent an infinite loop:

```
if (fix(N) ~= N) | (N < 0)
    disp 'Provide a positive
          integer number!'
    return;
end
```

- If no check can be done before a while-loop, you may want to stop after x loops

Functions - checking input

The whole factorial function, including comments:

```
function Z = fact_while(N)
    % This function computes a factorial of input value N
    % Usage   : fact_while(N)
    % N       : value of which the factorial is computed
    % returns: factorial of N

    % Catch non-integer case
    if (fix(N) ~= N) | (N<0)
        disp 'Provide a positive integer number!'
        return;
    end

    Z = 1;
    i = 1;
    while (i<=N)
        Z = Z*i;
        i = i+1;
    end
```

Recursion

- In order to understand recursion, one must first understand recursion
- A recursive function is called by itself (a function within a function)
 - This could lead to infinite calls;
 - A base case is required so that recursion is stopped;
 - Base case does not call itself, simply returns.



Recursion: example

```
function out = mystery(a,b)
if (b == 1)
    % Base case
    out = a;
else
    % Recursive function call
    out = a + mystery(a,b-1);
end
```

- What does this function do?
- Can you spot the error?
- How deep can you go? Which values of b don't work anymore?

Recursion: exercise

Create a function computing the factorial of N , based on recursion.

```
function res = fact_recursive(x)

% Catch non-integer case
if (fix(x) ~= x) | (x<0)
    disp 'You should provide a positive integer number
          only'
    return;
end

if (x > 1)
    res = x*fact_recursive(x-1);
else
    res = 1;
end

end
```

Part II

Code management

Today's outline

⑥ Coding in style

⑦ Error management

⑧ Visualisation

⑨ Conclusions

If anything sticks today, let it be this

Your code will not be understood by anyone

That includes future-you

Code organization

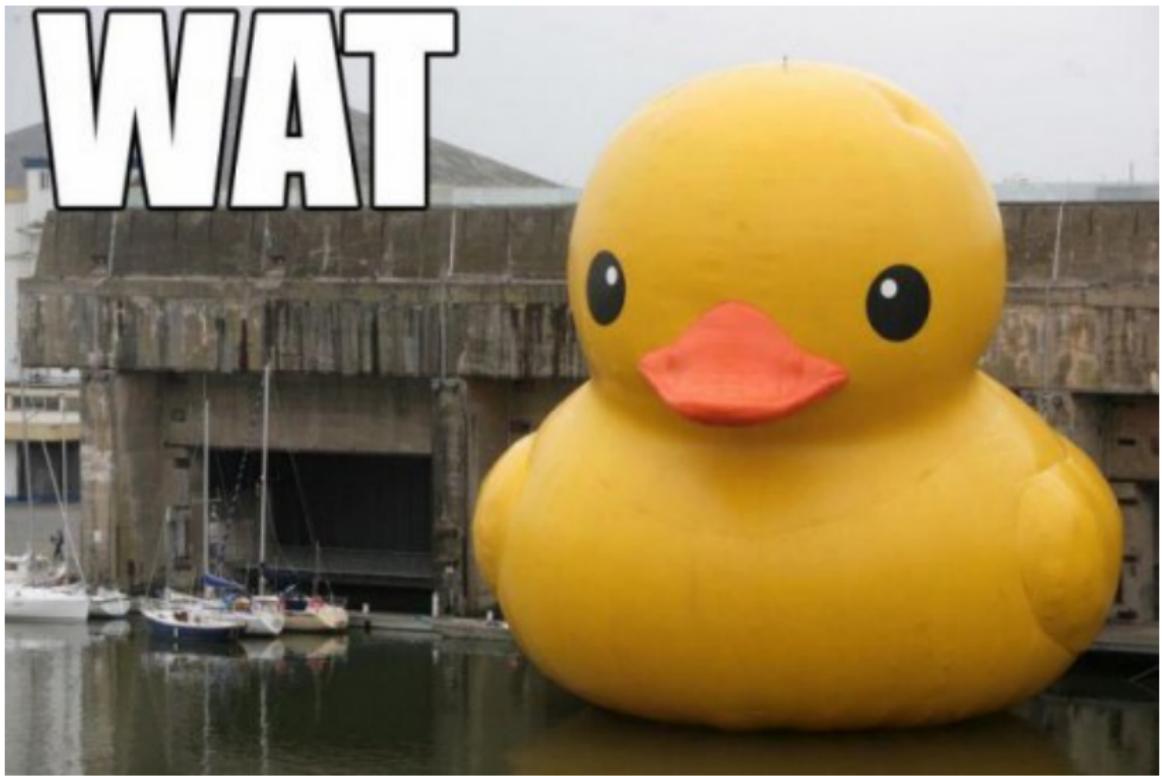
- Optimization of a code is time-consuming and complicated
- The more you optimize your code, the less readable it becomes
- But... You can write it in a such way that it will be flexible and easy to maintain
- Especially important in team work
- Any person has its own handwriting. Any programmer has its own coding style.

The coding style ≡ handwriting...

Interpret the following code

```
s=checksc();  
if(s==true)  
a=cb();  
b=cfrsp();  
if(a<5)  
if(b>5)  
a=gtbs();  
end  
if(a>b)  
ubx();  
end  
end  
else  
brn();  
gtbs();  
end
```

WAT



Let's change that a bit... Indentation

Shown here with 2 spaces of indentation, Matlab uses 4 by default!

```
s=checksc();  
if(s==true)  
a=cb();  
b=cfrsp();  
if(a<5)  
if(b>5)  
a=gtbs();  
end  
if(a>b)  
ubx();  
end  
end  
else  
brn();  
gtbs();  
end
```

```
s = checksc();  
if (s == true)  
    a = cb();  
    b = cfrsp();  
    if (a < 5)  
        if (b > 5)  
            a = gtbs();  
        end  
        if (a > b)  
            ubx();  
        end  
    end  
else  
    brn();  
    gtbs();  
end
```

Readable variables and function names

```
s = checksc();
if (s == true)
    a = cb();
    b = cfrsp();
    if (a < 5)
        if (b > 5)
            a = gtbs();
        end
        if (a > b)
            ubx();
        end
    end
else
    brn();
    gtbs();
end
```

```
IAmFree = checkSchedule();
if (IAmFree == true)
    books = countBooks();
    shelfSize =
        countFreeSpaceShelf();
    if (books < 5)
        if (shelfSize > 5)
            books = goToBookStore();
        end
        if (books > shelfSize)
            useBox();
        end
    end
else
    burnBooks();
    goToBookStore();
end
```

Get rid of obscure constants in the code

```
IAmFree = checkSchedule();
if (IAmFree == true)
    books = countBooks();
    shelfSize =
        countFreeSpaceShelf();
    if (books < 5)
        if (shelfSize > 5)
            books = goToBookStore();
        end
        if (books > shelfSize)
            useBox();
        end
    end
else
    burnBooks();
    goToBookStore();
end
```

```
IAmFree = checkSchedule();
if (IAmFree == true)
    books = countBooks();
    shelfSize =
        countFreeSpaceShelf();
    if (books < maxShelfSize)
        if (shelfSize >
            minBooksNeeded)
            books = goToBookStore();
        end
        if (books > shelfSize)
            useBox();
        end
    end
else
    burnBooks();
    goToBookStore();
end
```

That's more like it!

```
s=checksc();
if(s==true)
a=cb();
b=cfrsp();
if(a<5)
if(b>5)
a=gtbs();
end
if(a>b)
ubx();
end
end
else
brn();
gtbs();
end
```

```
IAmFree = checkSchedule();
if (IAmFree == true)
books = countBooks();
shelfSize = countFreeSpaceShelf();
if (books < maxShelfSize)
if (shelfSize > minBooksNeeded)
books = goToBookStore();
end
if (books > shelfSize)
useBox();
end
end
else
burnBooks();
goToBookStore();
end
```

Writing readable code

Good code reads like a book.

- When it doesn't, make sure to use comments. In Matlab, everything following `% is a comment`
- Prevent “smart constructions” in the code
- Re-use working code (i.e. create functions for well-defined tasks).
- Documentation is also useful, but hard to maintain. (Matlab comes with a function that generates reports from comments)

How not to comment

- Useless:

```
% Start program
```

- Obvious:

```
if (a > 5)    % Check if a is greater than 5
    ...
end
```

- Too much about the life:

```
% Well... I do not know how to explain what is going on
% in the snippet below. I tried to code in the night
% with some booze and it worked then, but now I have a
% strong hangover and some parameters still need to be
% worked out...
```

- ...

```
% You may think that this function is obsolete, and doesn't seem to
% do anything. And you would be correct. But when we remove this
% function for some reason the whole program crashes and we can't
% figure out why, so here it will stay.
```

Adding comments to our program

```
IAmFree = checkSchedule();
if (IAmFree == true)
% Count books and amount of free space on a shelf.
% If minimum number of books I need is less than a
% shelf capacity, go shopping and buy additional
% literature. If the amount of books after the
% shopping is too big, use boxes to store them.
books = countBooks();
shelfSize = countFreeSpaceShelf();

...
else
burnBooks();
goToBookStore();
end
```

If anything sticks today, let it be this

Your code will not be understood by anyone

That includes future-you

Use comments and code to document design and purpose (functionality), not mechanics (implementation).

Use consistent and sensible naming of functions and variables.

Today's outline

⑥ Coding in style

⑦ Error management

⑧ Visualisation

⑨ Conclusions

Errors in computer programs

The following symptoms can be distinguished:

- Unable to execute the program
- Program crashes, warnings or error messages
- Never-ending loops
- Wrong (unexpected) result

Three error categories:

Syntax errors You did not obey the language rules. These errors prevent running or compilation of the program.

Runtime errors Something goes wrong during the execution of the program resulting in an error message (problem with input, division by zero, loading of non-existent files, memory problems, etc.)

Semantic errors The program does not do what you expect, but does what have told it to do.

A convenient tool: the debugger

- No-one can write a 1000-line code without making errors
 - If you can, please come work for us
- One of the most important skills you will acquire is debugging.
- Although it can be frustrating, debugging is one of the most intellectually rich, challenging, and interesting parts of programming.
- In some ways, debugging is like detective work. You are confronted with clues, and you have to infer the processes and events that led to the results you see.

"When you have eliminated the impossible, whatever remains, however improbable, must be the truth."
— A. Conan Doyle, The Sign of Four

A convenient tool: the debugger

The debugger can help you to:

- Pause a program at a certain line: set a *breakpoint*
- Check the values of variables during the program
- Controlled execution of the program:
 - One line at a time
 - Run until a certain line
 - Run until a certain condition is met (conditional breakpoint)
 - Run until the current function exits
- Note: You may end up in the source code of Matlab functions!
- Check Canvas (Matlab Crash Course section) for a movie that demonstrates the debugger.

About testcases (validation)

- Testcases: run the program with parameters such that a known result is (should be) produced.
- Testcases: what happens when unforeseen input is encountered?
 - More or fewer arguments than anticipated? (Matlab uses `varargin` and `nargin` to create a varying number of input arguments, and to check the number of given input arguments)
 - Other data types than anticipated? How does the program handle this? Warnings, error messages (crash), NaN or worse (a continuing program)?
- For physical modeling, we typically look for analytical solutions
 - Sometimes somewhat stylized cases
 - Possible solutions include Fourier-series
 - Experimental data

Today's outline

⑥ Coding in style

⑦ Error management

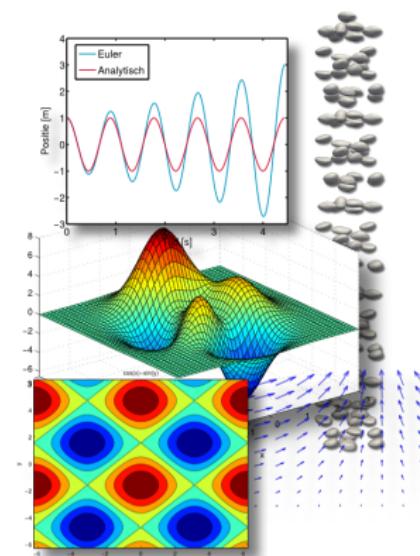
⑧ Visualisation

⑨ Conclusions

Data visualisation

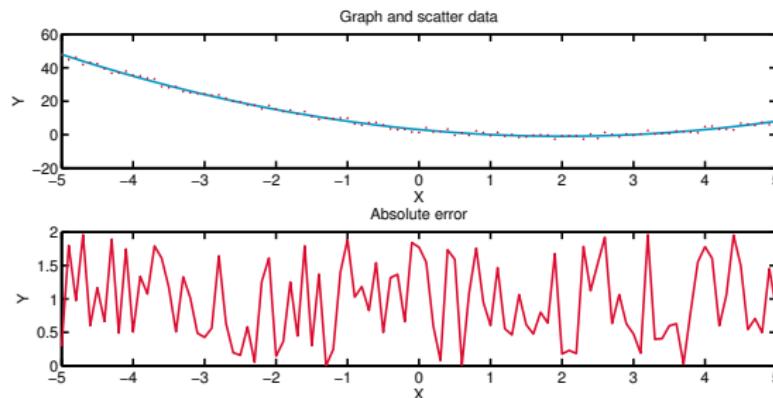
Modeling can lead to very large data sets, that require appropriate visualisation to convey your results.

- 1D, 2D, 3D visualisation
- Multiple variables at the same time (temperature, concentration, direction of flow)
- Use of colors, contour lines
- Use of stream lines or vector plots
- Animations



Plotting

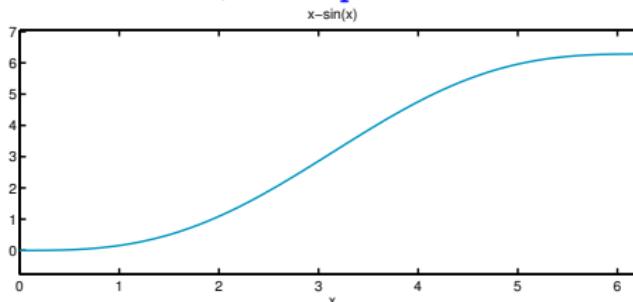
```
x = -5:0.1:5;
y = x.^2-4*x+3;
y2 = y + (2-4*rand(size(y)));
subplot(2,1,1); plot(x,y,'-',x,y2,'r.');
xlabel('X'); ylabel('Y'); title('Graph and Scatter');
subplot(2,1,2); plot(x,abs(y-y2),'r-');
xlabel('X'); ylabel('Y'); title('Absolute error');
```



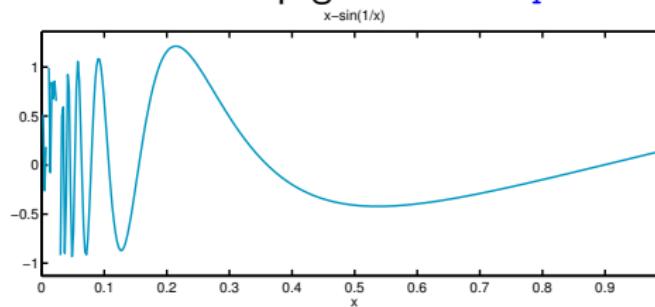
Plotting (2)

Easy plotting of functions can be done using the `ezplot` function:

`ezplot('x-sin(x)', [0 2*pi]):`

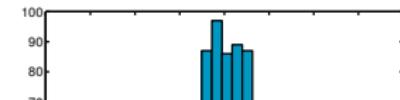
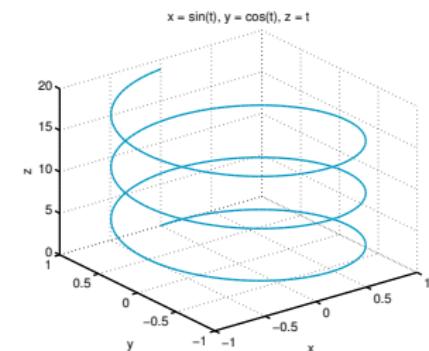
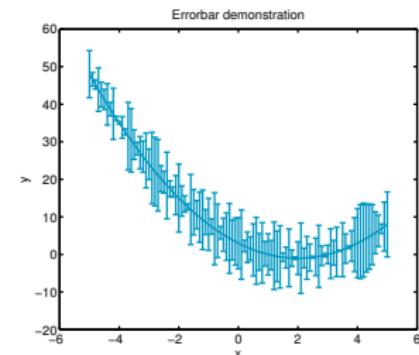


Be careful with steep gradients: `ezplot('x-sin(1/x)', [0 1])`



Other plotting tools

- Errorbars: `errorbar(x,y,err)`
- 3D-plots: `plot3(x,y,z)`
- Histograms: `histogram(x,20)`

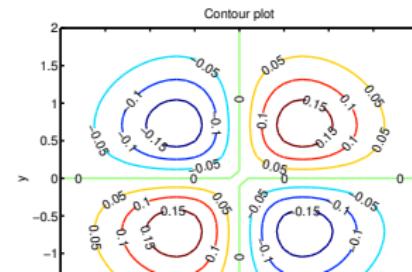
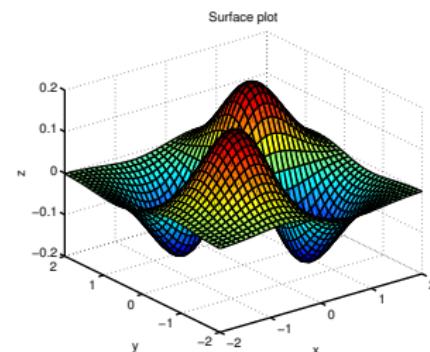


Multi-dimensional data

Matlab typically requires the definition of rectangular grid coordinates using `meshgrid`:

```
[x y] = meshgrid(-2:0.1:2,  
                    -2:0.1:2);  
z = x .* y .* exp(-x.^2 - y.^2);
```

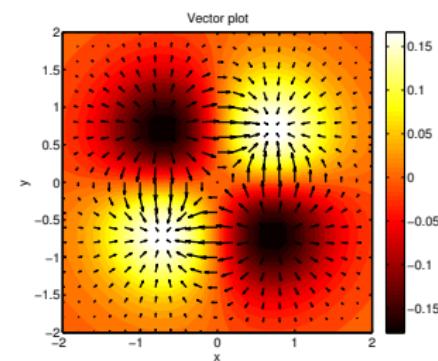
- Surface plot
- Contour plot
- Waterfall
- Ribbons



Vector data

The gradient operator, as expected, is used to obtain the gradient of a scalar field. Colors can be used in the background to simultaneously plot field data:

```
[x y] = meshgrid(-2:0.2:2,  
                   -2:0.2:2);  
z = x .* y .* exp(-x.^2 - y.^2)  
[dx dy] = gradient(z,8,8)  
  
% Background  
contourf(x,y,z,30,'LineColor','  
          none');  
colormap(hot); colorbar;  
  
axis tight; hold on;  
  
% Vectors  
quiver(x,y,dx,dy,'k');
```



Today's outline

⑥ Coding in style

⑦ Error management

⑧ Visualisation

⑨ Conclusions

In conclusion...

- Matlab: A versatile development environment, with excellent vector and matrix computations
- Programming basics: variables, operators and functions, locality of variables, recursive operations
- For now: exercises 1-4 (basics), 5+6 (advanced).
- Preparation for next lecture: familiarize with the concepts, especially part 1 of these slides.