Matlab and Programming 1

Programming basics and algorithms

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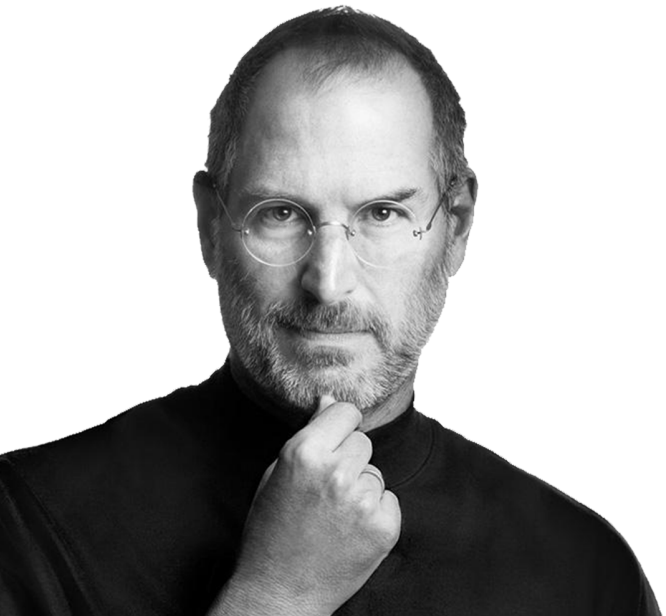
Today's outline

Programming

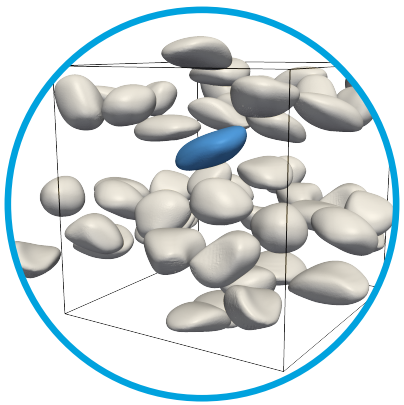
"Everybody in this country should learn to program a computer, because it teaches you to think.."

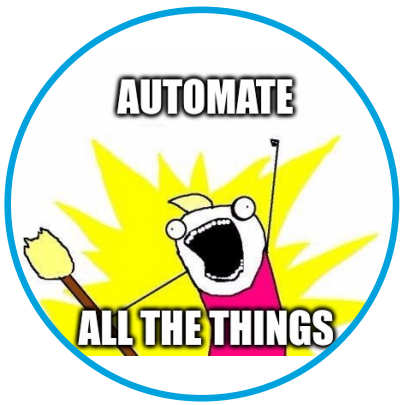
—Steve Jobs



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, such as solving a system of equations or finding the roots of a polynomial
- It can also be a symbolic computation, such as searching and replacing text in a document
- A program may even be used to compile another program
- A program consists of one or more *algorithms*

Getting started

- Use an *integrated development environment*
  - Matlab
  - MS Visual Studio/Code
  - Eclipse
  - Dev C++
  - IDLE, Canopy (express)
- Create a simple program:
  - Hello world
  - Find the roots of a parabola
  - Find the greatest common divisor of two numbers

Some often used programming languages

Python

- Many functionalities available
- Smooth learning curve
- Slow compared to compiled languages
- Many freely available editors

C / C++ / C#

- Many functionalities available
- Steeper learning curve
- Needs compilation, very fast (HPC)
- Freely available (gcc, MSVC)

Pascal

- Limited number of libraries available
- Steep learning curve
- Compiled language, may be fast
- Some free compilers (fpc)

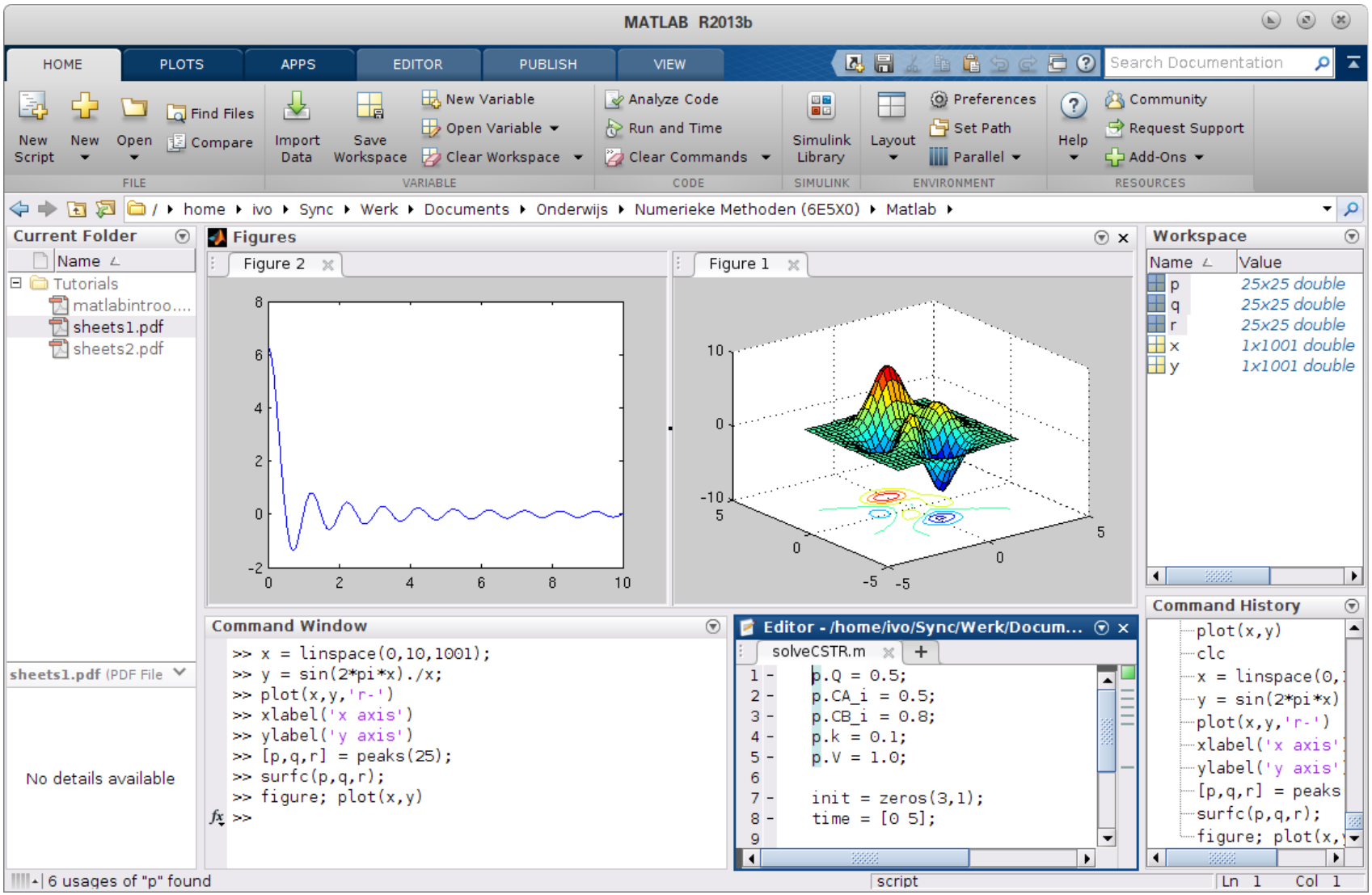
Spreadsheet (Excel, Google Docs, ...)

- High availability
- Low learning curve
- Very limited for larger problems, unbeatable for quick calculations
- Not always free

Matlab

- Many functionalities built-in (80+ toolkits!)
- Slow compared to compiled languages
- Fairly smooth learning curve
- Needs a license (alternatives: SciLab, GNU Octave)

Versatility of Matlab

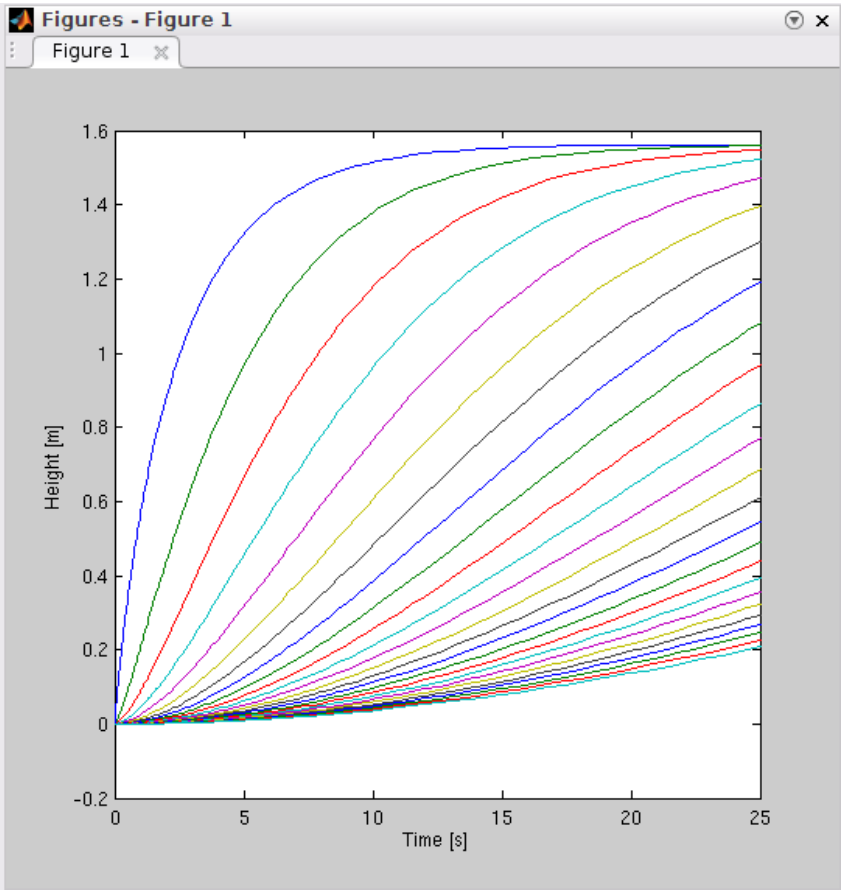


Versatility of Matlab: ODE solver

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

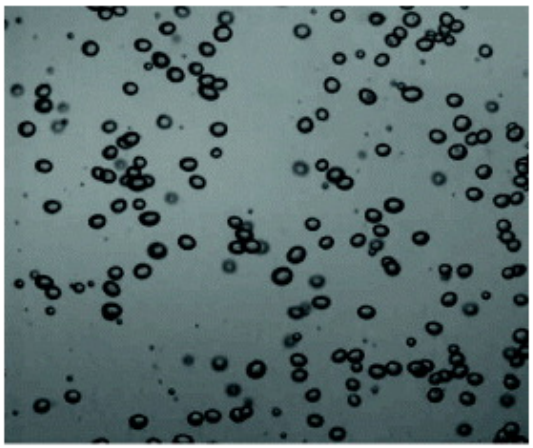
solveTankSeries.m | tankSeries.m

```
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]');
```

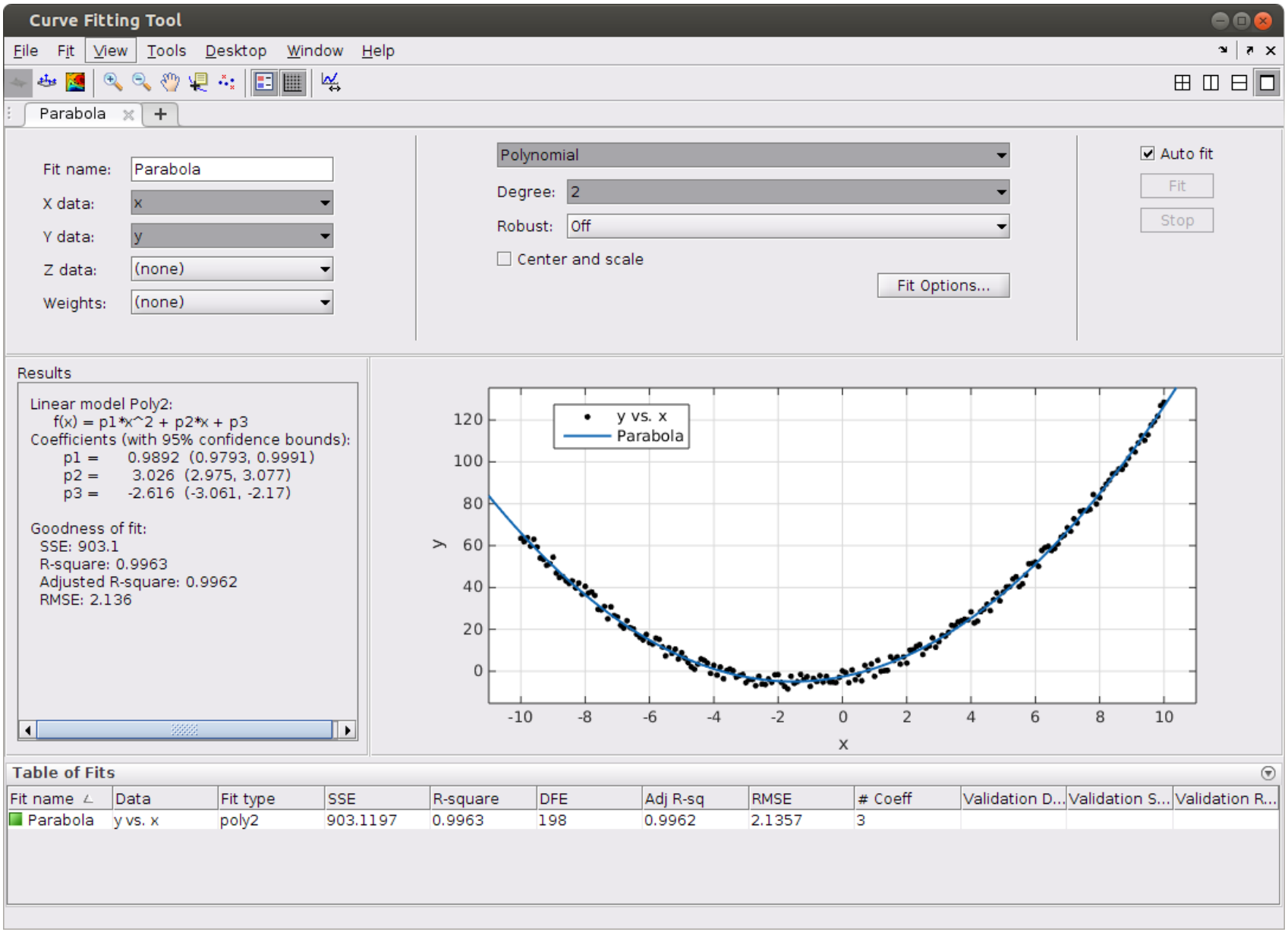


Versatility of Matlab: Image analysis

```
I = imread('bubbles.png');
BW = rgb2gray(I);
E = edge(BW, 'canny');
F = imfill(E, 'holes');
result = regionprops(F);
```



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

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`.

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

```
>> x = [ 5 20 30 50 55 ]
>> y = [ 0.08 0.015 0.009 0.006 0.0055]
```

```
>> plot(x,y)
```

```
>> plot(x,y,'*')
```

```
>> plot(x,y,'r--')
```

```
>> plot(x,y,'ko-','LineWidth',2)
```

```
>> xlabel('Temperature [^\circC]')
>> 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?
- How to obtain the maximum for each row?
- Use a vector multiplication to compute the following matrix:

$$A = \begin{bmatrix} 1 & 1 & 1 & 1 \\ 2 & 2 & 2 & 2 \\ 3 & 3 & 3 & 3 \\ 4 & 4 & 4 & 4 \end{bmatrix}$$

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).

Today's outline

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

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 acces 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!

Exercise: 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
```

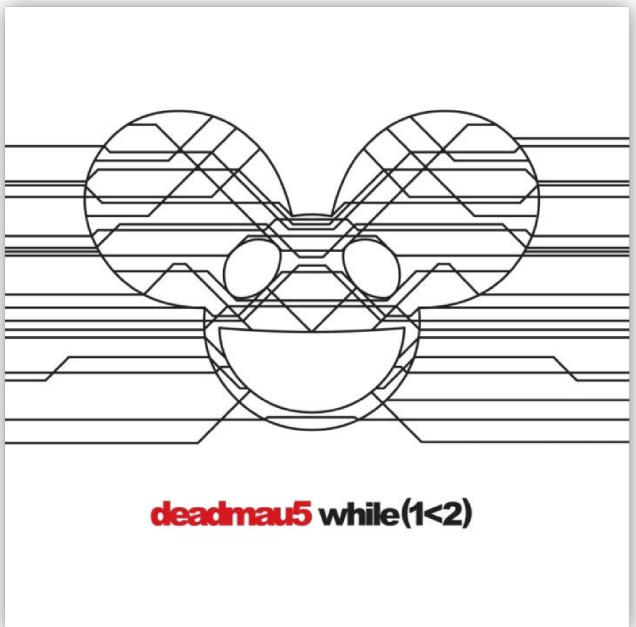
Function

```
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

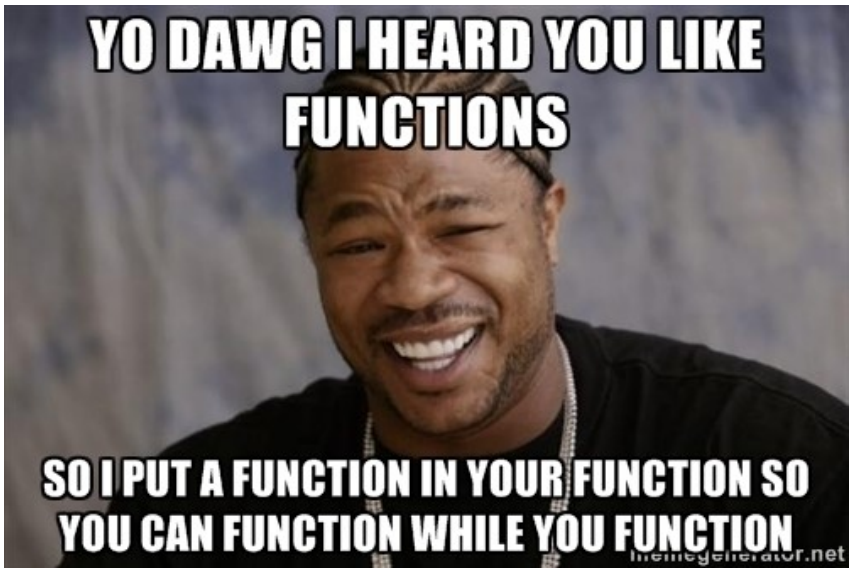
Functions - checking input

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
```

Today's outline

In conclusion...

- Matlab: A versatile development environment, with excellent vector and matrix computations
- Programming basics: variables, operators and functions, locality of variables, recursive operations

- Next lecture: advanced practices (prepare, read instructions on Canvas)
- For now: exercises 1-4 (basics), 5+6 (advanced).