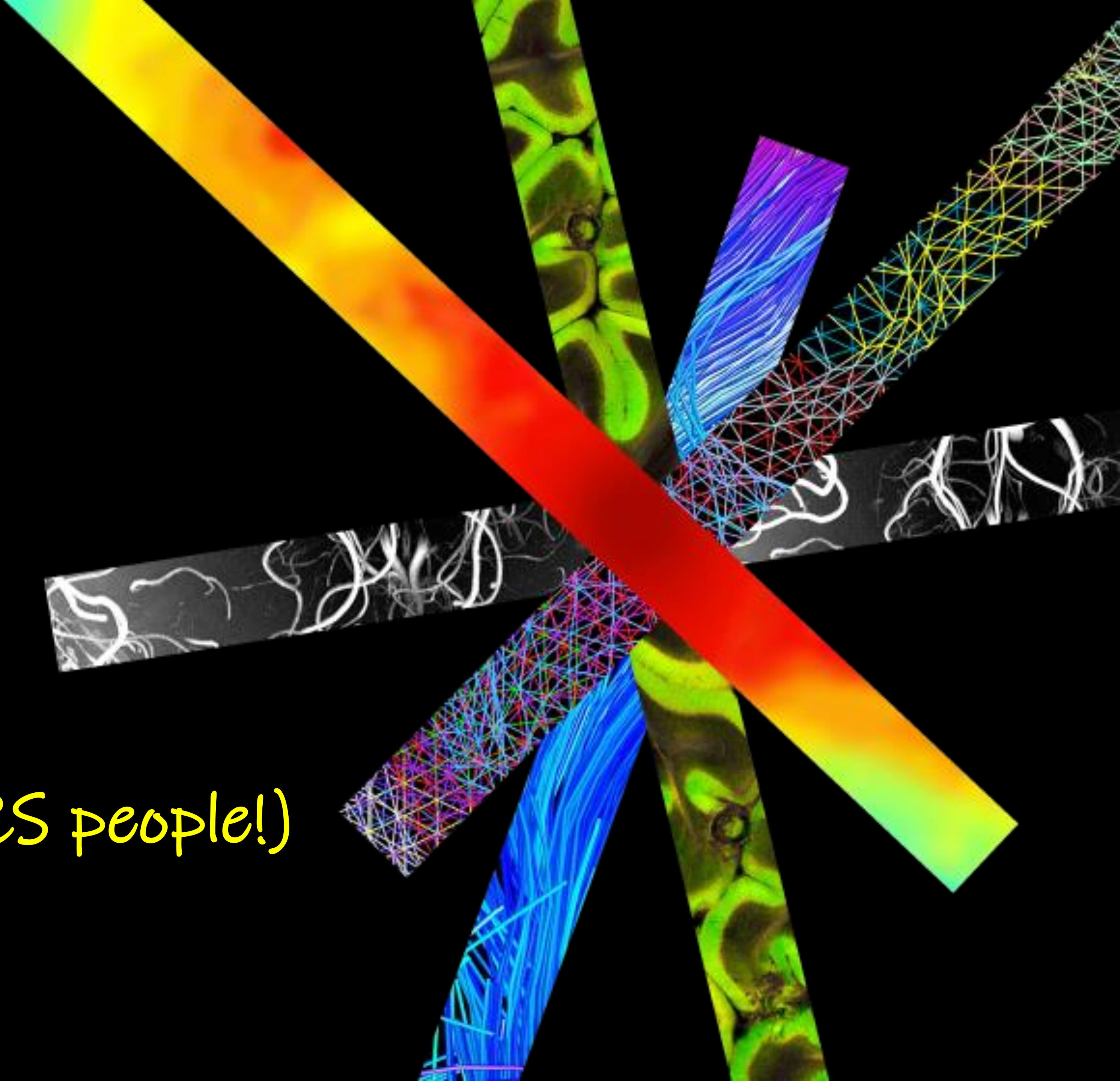
Athinoula A.
Martinos
Center
For Biomedical Imaging



Introduction to MATLAB® (for non-CS people!)

Michele Scipioni, PhD

3/12/2020

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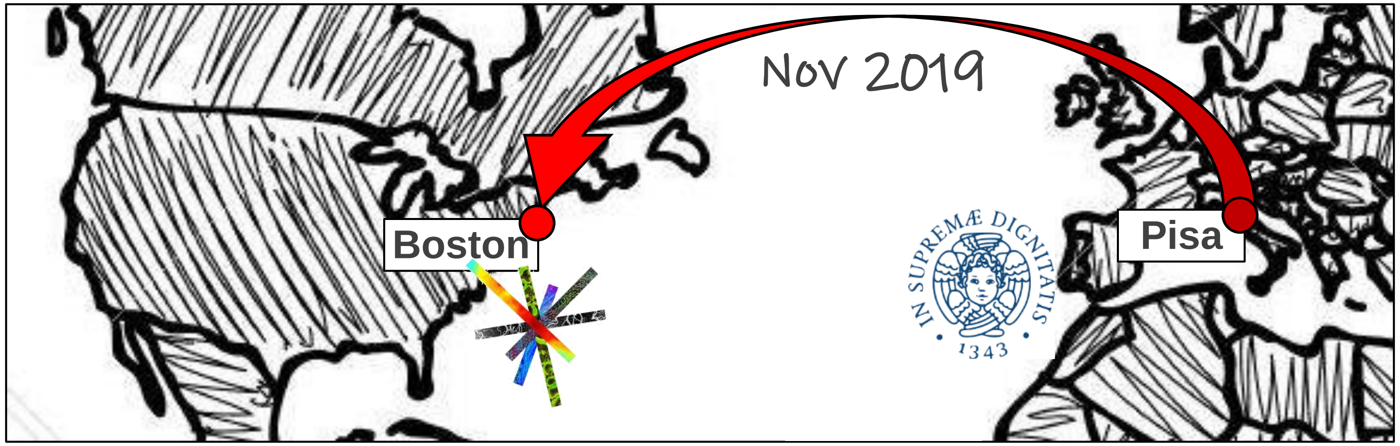
Who am I?

Michele Scipioni

Biomedical Engineer



MSc + PhD @ University of Pisa, Italy

#PET
#ImageReconstruction
#KineticModeling

Postdoc @ Martinos Center

#PET + PET/MR
#ImageReconstruction
#KineticModeling
#PET/MR tech design and development

Ciprian Catana's PET-MR lab

Overview

- **WHAT?**
- **WHY?**
- **HOW?**
  - GETTING STARTED
  - SCRIPTS, FUNCTIONS, AND THE EDITOR
  - VISUALIZATION TOOLS
- **BUT … CAN I STILL USE IT, IF I DON'T KNOW HOW TO CODE?**

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General background: what are we talking about?

What is MATLAB?

MATLAB = **MAT**rix **LAB**oratory

- High-level ***scripting*** language
- Interactive ***visualization*** tool
- Interactive ***computation*** tool

What can I do with MATLAB?

- **Automate** complex data processing streams.
- **Analyze** data.
- **Develop** algorithms.
- **Create** models and applications.
- **Write your own** data analysis/computation tools.

MATLAB
is complete package made of a programming language, computing environment, IDE, and many toolboxes for data processing and plotting.

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Matlab *vs* C / C++ / Fortran

high level language

easy to learn

professionally developed **tools and built-in functions**

user-friendly **GUI**

(very expensive) **commercial product**

compiled language

(significantly) faster

general-purpose

Matlab *vs* Python

interpreted languages
easy multi-OS **portability**
sub-optimal **performance** (wrt C/C++)

high level language

easy to learn

professionally developed **tools and built-in functions**

user-friendly **GUI**

(very expensive) **commercial product**

general-purpose

open and free

open source libraries

go-to language for **machine learning and data science** (at the moment)

Matlab *vs* R

faster!

easy to learn and intuitive

professionally developed **tools and built-in functions**

user-friendly **GUI**

‘can’ do statistics and ML, but also much more

(very expensive) **commercial product**

syntax closer to conventional languages

open and free

open source libraries

go-to language **data analysis and statistics** (at the moment)

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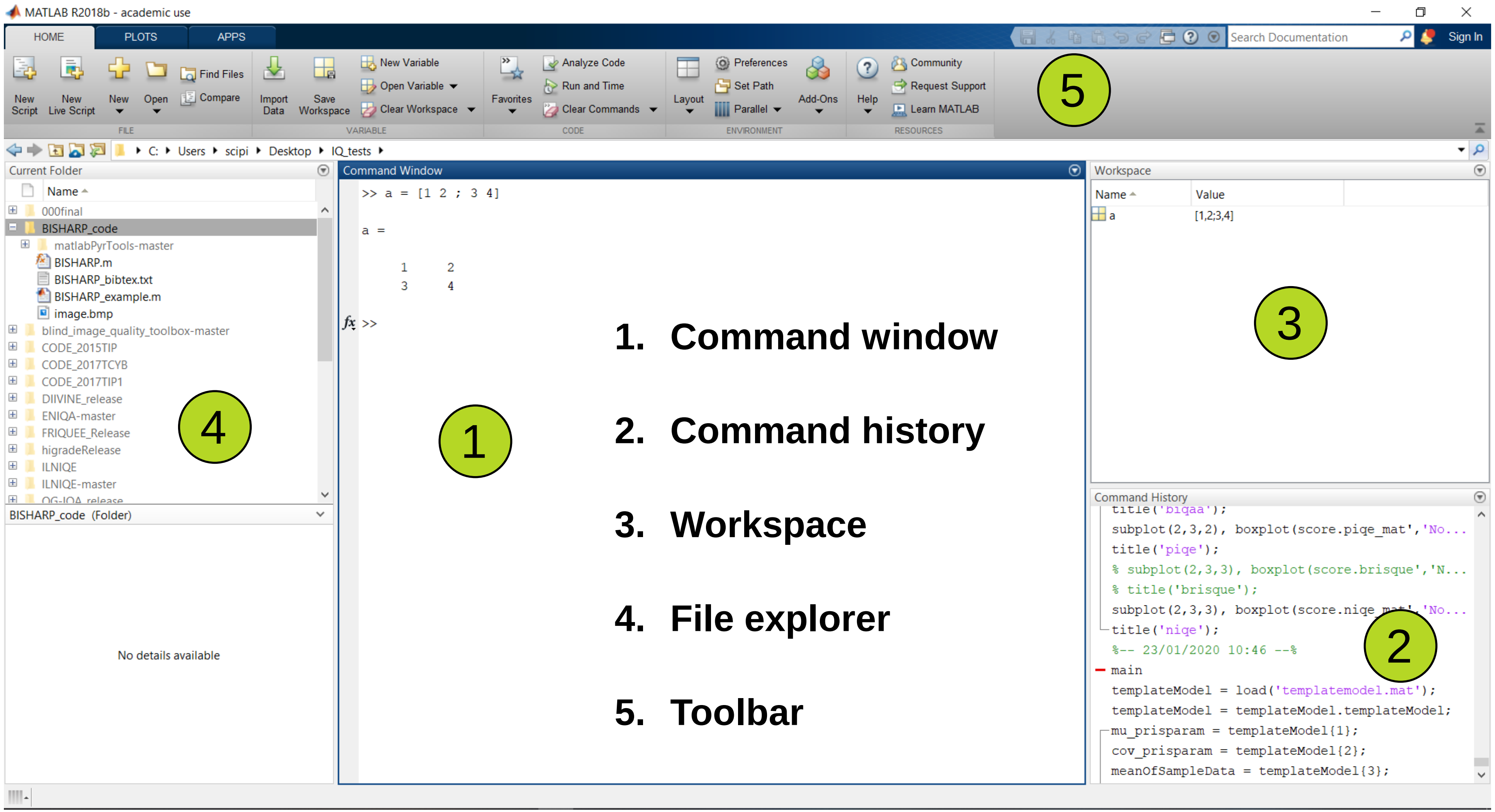
MATLAB Graphical User Interface (GUI)



1. Command window
2. Command history
3. Workspace
4. File explorer
5. Toolbar

MATLAB syntax – Looking for help!

Don’t be scared to ask for help!

In many case, the documentation texts are quite informative and educational.

```
>> help          % lists available packages/toolboxes on system.
>> help elfun    % lists functions in elementary functions package
>> help sin      % instructions on the sine function
>> lookfor sine  %  if you don’t know the function name …
>> doc sin       % for full details o ffunction
```

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MATLAB syntax – Looking for help!

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In many case, the documentation texts are quite informative and educational.

```
>> help
>> help elfun
>> help sin
>> lookfor sine
>> doc sin
```

```
>> help sin
 sin    Sine of argument in radians.
    sin(X) is the sine of the elements of X.

    See also asin, sind, sinpi.

    Reference page for sin
    Other functions named sin

>>
```

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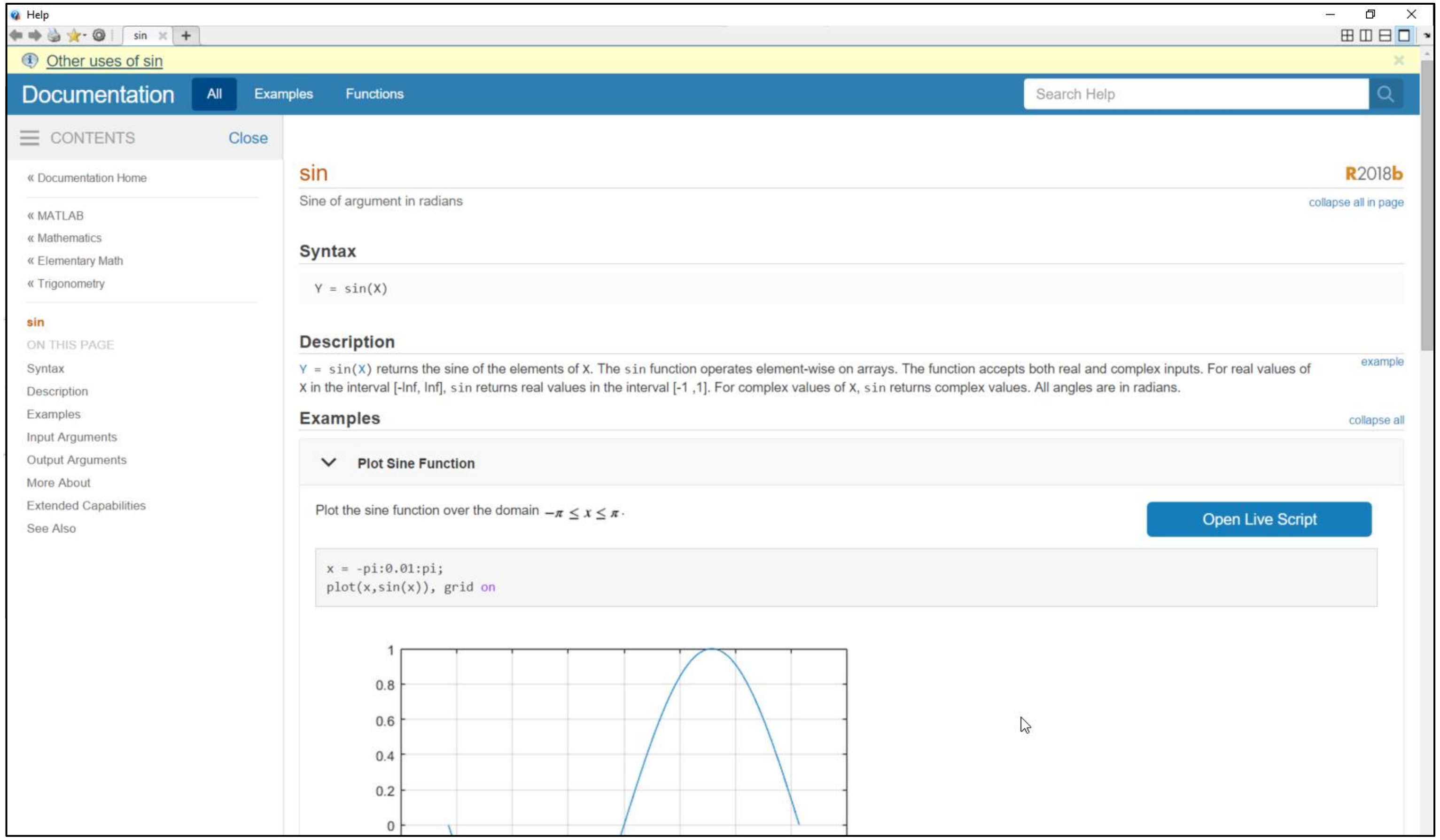

MATLAB syntax – Matrices, vectors, arrays …

Scalar

```
>> s = 5; % no need to specify data type (default is double)
```

Vector

```
>> a = [1, 2, 3];    % row vector
>> b = [4; 5; 6];    % column vector
```

Matrix

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

MATLAB syntax – Matrices, vectors, arrays …

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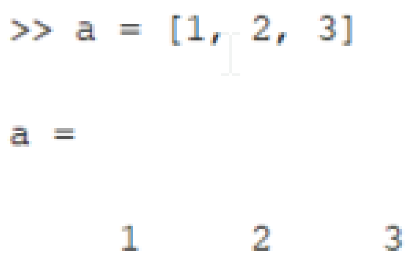

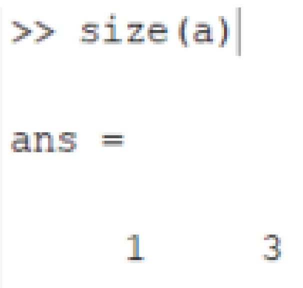

Matrix

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

MATLAB syntax – Matrices, vectors, arrays …

Scalar

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>> s = 5; % no need to specify data type (default is double)
```

Vector

```
>> a = [1, 2, 3];     % row vector
>> b = [4; 5; 6];     % column vector
```

```
>> b = [4; 5; 6]

b =

     4
     5
     6
```

```
>> size(b)

ans =

     3     1
```

Matrix

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

MATLAB syntax – Matrices, vectors, arrays …

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Vector

```
>> a = [1, 2, 3];    % row vector
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```

Matrix

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

```
A =

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

Use percent (%) sign to start a comment (everything after it **IS NOT** code)

Suppress (interactive console) output by adding a **semicolon** (;) at the end of each line

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

A =

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

Matrix

```
>> A = [1, 2, 3 ; 4, 5, 6 ; 7, 8, 9];     % 3 x 3 matrix
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MATLAB syntax – Matrices, vectors, arrays …

FUNCTIONS TO CREATE MATRICES

```
>> zeros(5,3);   % All zeros
>> ones(8,5);    % All ones
>> eye(5);       % Identity matrix
>> rand(3,9);    % Uniformly distributed random numbers (between 0 and 1)
>> randn(10,5);  % Normally distributed random numbers (mean 0 and var 1)
```

MATLAB syntax – Matrices, vectors, arrays …

MATRIX INDEXING / SLICING

- In MATLAB matrix and vector **indexing start from 1 (not from 0).**
- It uses a **column-major** convention (it affects reshaping and transpositions)

```
A =

    68    59    96    82    48    76    78
    66    23    55    25    36    76    94
    17    76    14    93    84    39    13
    12    26    15    35    59    57    57
    50    51    26    20    55     8    47
    96    70    85    26    92     6     2
    35    90    26    62    29    54    34
```

```
>> A(3,2)            % Access a single element (3rd row, 2nd col)
```

```
>> disp(A(3,2))
    76
```

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MATLAB syntax – Matrices, vectors, arrays …

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    96    70    85    26    92     6     2
    35    90    26    62    29    54    34
```

```
>> A(3,2)            % Access a single element (3rd row, 2nd col)
>> A(:,1)            % Select the whole 1° column
```

```
>> disp(A(:,1))
    68
    66
    17
    12
    50
    96
    35
```

MATLAB syntax – Matrices, vectors, arrays …

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    50    51    26    20    55     8    47
    96    70    85    26    92     6     2
    35    90    26    62    29    54    34
```

```
>> A(3,2)        % Access a single element (3rd row, 2nd col)
>> A(:,1)        % Select the whole 1° column
>> A(2,2:5)      % Select a subset of 2° row
```

```
>> disp(A(2,2:5))
    23    55    25    36
```

MATLAB syntax – Matrices, vectors, arrays …

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    50    51    26    20    55     8    47
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```

```
>> A(3,2)          % Access a single element (3rd row, 2nd col)
>> A(:,1)          % Select the whole 1° column
>> A(2,2:5)        % Select a subset of 2° row
>> sum(A(2,:))     % Sum all elements of 2° row
```

```
>> disp(sum(A(2,:)))
   375
```

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MATLAB syntax – Matrices, vectors, arrays …

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A =

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96	70	85	26	92	6	2
35	90	26	62	29	54	34

```
>> A(3,2)          % Access a single element (3rd row, 2nd col)
>> A(:,1)          % Select the whole 1° column
>> A(2,2:5)        % Select a subset of 2° row
>> sum(A(2,:))     % Sum all elements of 2° row
>> max(A(:,3))     % Max value of 3° column
```

```
>> disp(max(A(:,3)))
   96
```

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MATLAB syntax – Matrices, vectors, arrays …

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```

```
>> A(3,2)               % Access a single element (3rd row, 2nd col)
>> A(:,1)               % Select the whole 1° column
>> A(2,2:5)             % Select a subset of 2° row
>> sum(A(2,:))          % Sum all elements of 2° row
>> max(A(:,3))          % Max value of 3° column
>> find(isprime(A))     % Index of prime numbers among all elements
```

```
>> disp((isprime(A)))
   0   1   0   0   0   0   0
   0   1   0   0   0   0   0
   1   0   0   0   0   0   1
   0   0   0   0   1   0   0
   0   0   0   0   0   0   1
   0   0   0   0   0   0   1
   0   0   0   0   1   0   0
```

```
>> disp(find(isprime(A))')
     3     8     9    32    35    45    47    48
```

column-major indexes!

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MATLAB syntax – Matrices, vectors, arrays …

VECTOR OPERATIONS

```
>> a + 3    % Add a scalar to a vector
>> a * 3    % Multiply a scalar and a vector
>> pinv(a)  % Moore-Penrose pseudoinverse
>> norm(b)  % norm of a vector
>> a’       % transpose
```

Elementwise ops [MUST BE *same* size!]

```
>> a + b    % vector addition
>> a - b    % vector subtraction
>> a .* b   % vector multplication
>> a ./ b   % vector division
```

MUST BE of *compatible* size!

```
>> a * c    % dot product
>> dot(a,c) % dot product
>> a / b    % equiv to a*pinv(b)
```

MATLAB syntax – Matrices, vectors, arrays …

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>> pinv(a)   % Moore-Penrose pseudoinverse
>> norm(b)   % norm of a vector
>> a'        % transpose
```

```
a = [1,2,3]
b = [4,5,6]
c = [7;8;9]
```

```
>> disp(a')
     1
     2
     3
```

Elementwise ops [MUST BE *same* size!]

```
>> a + b     % vector addition
>> a - b     % vector subtraction
>> a .* b    % vector multplication
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```

```
a = [1,2,3]
b = [4,5,6]
c = [7;8;9]
```

```
>> a .* b

ans =

     4    10    18
```

Elementwise ops [MUST BE *same* shape!]

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>> a'        % transpose
```

```
a = [1,2,3]
b = [4,5,6]
c = [7;8;9]
```

```
>> a ./ b

ans =

    0.2500    0.4000    0.5000
```

Elementwise ops [MUST BE *same* shape!]

```
>> a + b     % vector addition
>> a - b     % vector subtraction
>> a .* b    % vector multplication
>> a ./ b    % vector division
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>> norm(b)   % norm of a vector
>> a'        % transpose
```

```
a = [1,2,3]
b = [4,5,6]
c = [7;8;9]
```

```
>> a*c

ans =

    50
```

Elementwise ops [MUST BE *same* shape!]

```
>> a + b     % vector addition
>> a - b     % vector subtraction
>> a .* b    % vector multplication
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MATLAB syntax – Matrices, vectors, arrays …

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>> norm(b)  % norm of a vector
>> a'       % transpose
```

```
a = [1,2,3]
b = [4,5,6]
c = [7;8;9]
```

```
>> a/b

ans =

    0.4156
```

Elementwise ops [MUST BE *same* shape!]

```
>> a + b    % vector addition
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>> a .* b   % vector multplication
>> a ./ b   % vector division
```

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>> dot(a,c)   % dot product
>> a / b      % equiv to a*pinv(b)
```

MATLAB syntax – Matrices, vectors, arrays …

MATRIX OPERATIONS

```
>> A + 3      % Add a scalar
>> A * 3      % Multiply a scalar
>> sin(A)     % Elementwise sine
>> exp(A)     % Elementwise exponential
>> inv(A)     % Inverse of a matrix
```

```
>> pinv(A)  % Pseudoinverse of a matrix
>> det(A)   % Determinant of a matrix
>> A .^ 3   % Elementwise power
>> A`       % Transpose
```

Elementwise ops [MUST BE *same* shape!]

```
>> A + B      % Matrices addition
>> A .* B     % Matrices multplication
>> A ./ B     % Matrices division
```

MUST BE of *compatible* shape!

```
>> A * C    % Matrix multiplication
>> A * a    % Matrix-vector product
>> A / B    % A*inv(B)
>> A \ B    % inv(A)*B
```

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MATLAB syntax – Matrices, vectors, arrays …

MATRIX OPERATIONS

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>> A * a     % Matrix-vector product
>> A / B     % A*inv(B)
>> A \ B     % inv(A)*B
```

MATLAB syntax – ‘Unusual’ data structures

WHAT IS A ‘STRUCT’ IN MATLAB?

- A **structure array** is a data type that groups related data using data containers called **fields**.
- Each **field** can contain **any type of data**.
- Access data in a field using **dot notation** of the form ***structName.fieldName***

```
data.x = linspace(0,2*pi);
data.y = sin(data.x);
data.title = 'y = sin(x)'
```

```
data = struct with fields:
         x: [1x100 double]
         y: [1x100 double]
     title: 'y = sin(x)'
```

MATLAB syntax – ‘Unusual’ data structures

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- Access data in a field using **dot notation** of the form ***structName.fieldName***

```
field1 = 'f1';  value1 = zeros(1,10);
field2 = 'f2';  value2 = {'a', 'b'};
field3 = 'f3';  value3 = {pi, pi.^2};
field4 = 'f4';  value4 = {'fourth'};

s = struct(field1,value1,field2,value2,field3,value3,field4,value4)
```

```
s=2×4 struct
    f1
    f2
    f3
    f4
```

MATLAB syntax – 'Unusual' data structures

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field2 = 'f2';  value2 = {'a', 'b'};
field3 = 'f3';  value3 = {pi, pi.^2};
field4 = 'f4';  value4 = {'fourth'};

s = struct(field1,value1,field2,value2,field
```

```
s=2×4 struct
    f1
    f2
    f3
    f4
```

```
s(1)
```

```
ans = struct with fields:
    f1: [0 0 0 0 0 0 0 0 0 0]
    f2: 'a'
    f3: 3.1416
    f4: 'fourth'
```

```
s(2)
```

```
ans = struct with fields:
    f1: [0 0 0 0 0 0 0 0 0 0]
    f2: 'b'
    f3: 9.8696
    f4: 'fourth'
```

MATLAB syntax – 'Unusual' data structures

WHAT IS A 'STRUCT' IN MATLAB?

- A **structure array** is a data type that groups related data using data containers called **fields**.
- Each **field** can contain **any type of data**.
- Access data in a field using **dot notation** of the form ***structName.fieldName***

```
field1 = 'f1';  value1 = zeros(1,10);
field2 = 'f2';  value2 = {'a', 'b'};
field3 = 'f3';  value3 = {pi, pi.^2};
field4 = 'f4';  value4 = {'fourth'};

s = struct(field1,value1,field2,value2,field
```

```
s=2×4 struct
    f1
    f2
    f3
    f4
```

```
s(1)
```

```
ans = struct with fields:
    f1: [0 0 0 0 0 0 0 0 0 0]
    f2: 'a'
    f3: 3.1416
    f4: 'fourth'
```

```
s(2)
```

```
ans = struct with fields:
    f1: [0 0 0 0 0 0 0 0 0 0]
    f2: 'b'
    f3: 9.8696
    f4: 'fourth'
```

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MATLAB syntax – ‘Unusual’ data structures

WHAT ABOUT ‘CELL ARRAYS’?

- A **cell array** is a data type with ***indexed data containers*** called **cells**
- Each **cell** can contain **any type of data**.

Creation

When you have data to put into a cell array, create the array using the cell array **construction operator, {}.**

```
C = {'2017-08-16',[56 67 78]}
```

```
C=1×2 cell
    {'2017-08-16'}    {1x3 double}
```

```
C(2,:) = {'2017-08-17',[58 69 79]};
C(3,:) = {'2017-08-18',[60 68 81]}
```

```
C=3×2 cell
    {'2017-08-16'}    {1x3 double}
    {'2017-08-17'}    {1x3 double}
    {'2017-08-18'}    {1x3 double}
```

Indexing

When you index with **smooth parentheses, (),** the result is a cell array that is a subset of the cell

```
C(1,:)
```

```
ans=1×2 cell
    {'2017-08-16'}    {1x3 double}
```

When you index with **curly braces, {},** the result is the data that is contained in the specified cell.

```
C{1,2}
```

```
ans = 1×3

    56    67    78
```

MATLAB syntax – Control flow

‘IF - ELSE’ CONDITION

Use an if-else **condition to check the value** of some variable within the code:

```
a = randi(100,1);
if a < 30
  fprintf(‘%d is smaller than 30. \n’, a)
elseif a > 80
  fprintf(‘%d is larger than 80. \n’, a)
else
  X = [num2str(a), ‘ is between 30 and 80.’];
  disp(X)
end
```

MATLAB syntax – Control flow

‘IF - ELSE’ CONDITION

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```
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if a < 30
  fprintf(‘%d is smaller than 30. \n’, a)
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else
  X = [num2str(a), ‘ is between 30 and 80.’];
  disp(X)
end
```

MATLAB syntax – Control flow

‘IF - ELSE’ CONDITION

Use an if-else **condition to check the value** of some variable within the code:

```
a = randi(100,1);
if a < 30
   fprintf('%d is smaller than 30. \n', a)
elseif a > 80
   fprintf('%d is larger than 80. \n', a)
else
   X = [num2str(a), ' is between 30 and 80.'];
   disp(X)
end
```

MATLAB syntax – Control flow

'FOR' LOOPS

Use for-loops to execute iterations with a **know, and fixed number of repetitions**

```
for i=1:5                  % row index
  for j=1:3                % col index
     A(i, j) = i + j ;     % use loop iterable to index a matrix
  end
end                        % close each loop with an 'end'
```

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MATLAB syntax – Control flow

‘WHILE - BREAK’ LOOPS

Use **while-loops** to execute iterations with **unknown number of repetitions**.

Use a **break** command to exit the while once a certain condition is met.

```
%  find the root of the polynomial x3 - 2x - 5
a = 0; fa = -Inf;
b = 3; fb = Inf;
while b-a > eps*b
   x = (a+b) /2;    fx = x^3-2*x-5;
   if fx == 0
       break % Already found the root, exit the loop
   elseif sign(fx) == sign(fa) % This method only works when the polynomial
       a = x; fa = fx;         % is increasing in proximity of the root
   else
       b = x; fb = fx;
   end
end
```

Overview

- WHAT?
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  - VISUALIZATION TOOLS
- BUT … CAN I STILL USE IT, IF I DON’T KNOW HOW TO CODE?

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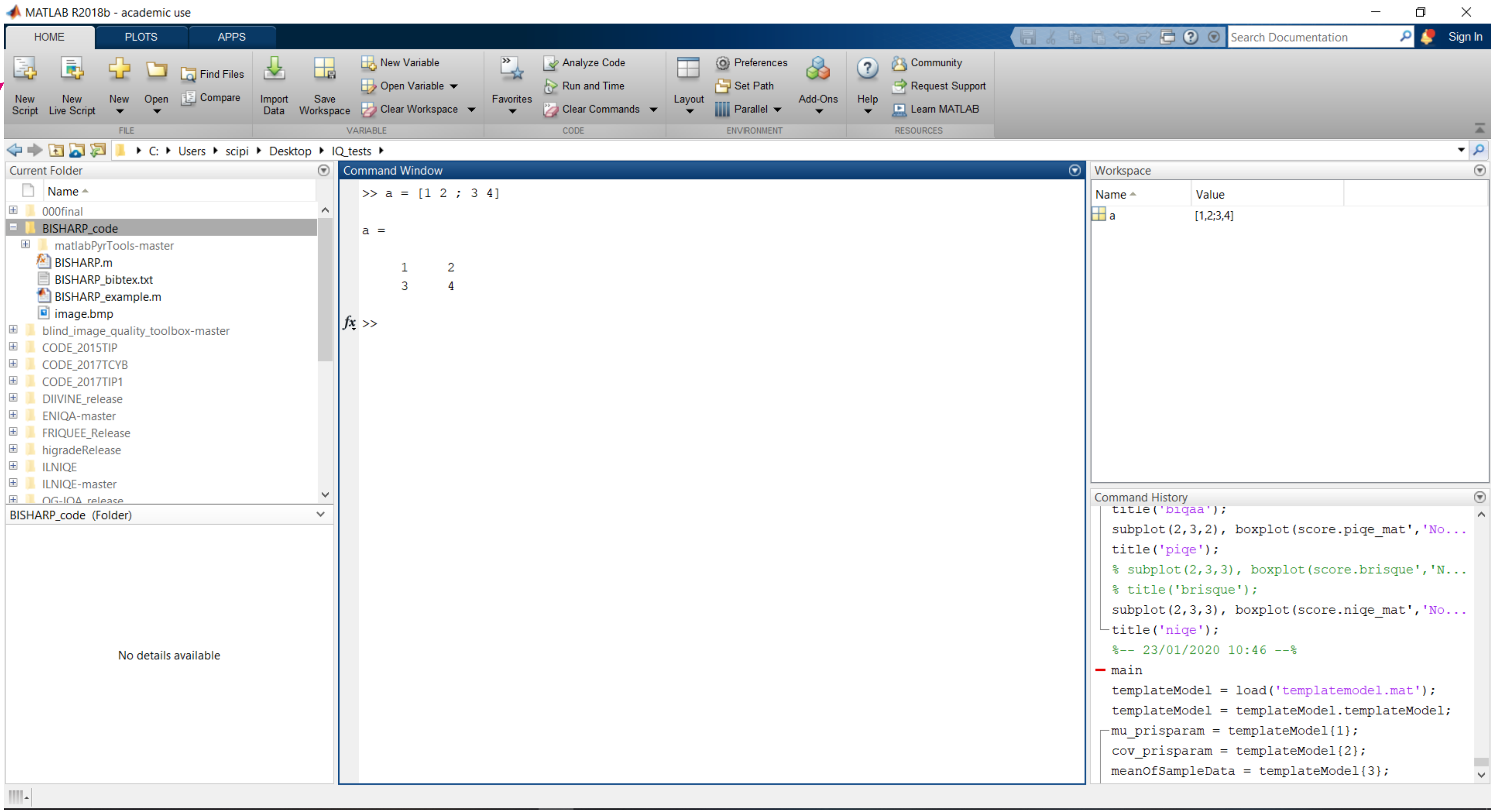
MATLAB’s Graphical User Interface (GUI)



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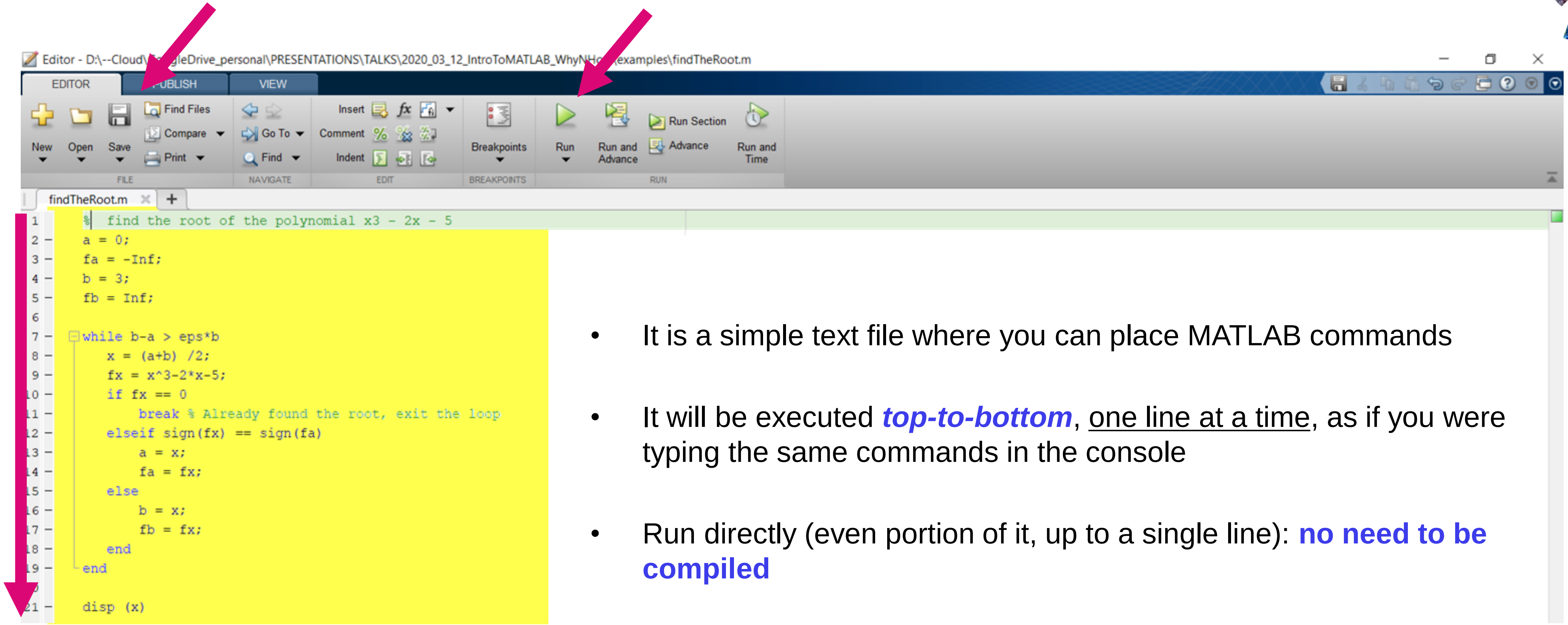
MATLAB's EDITOR – M-file

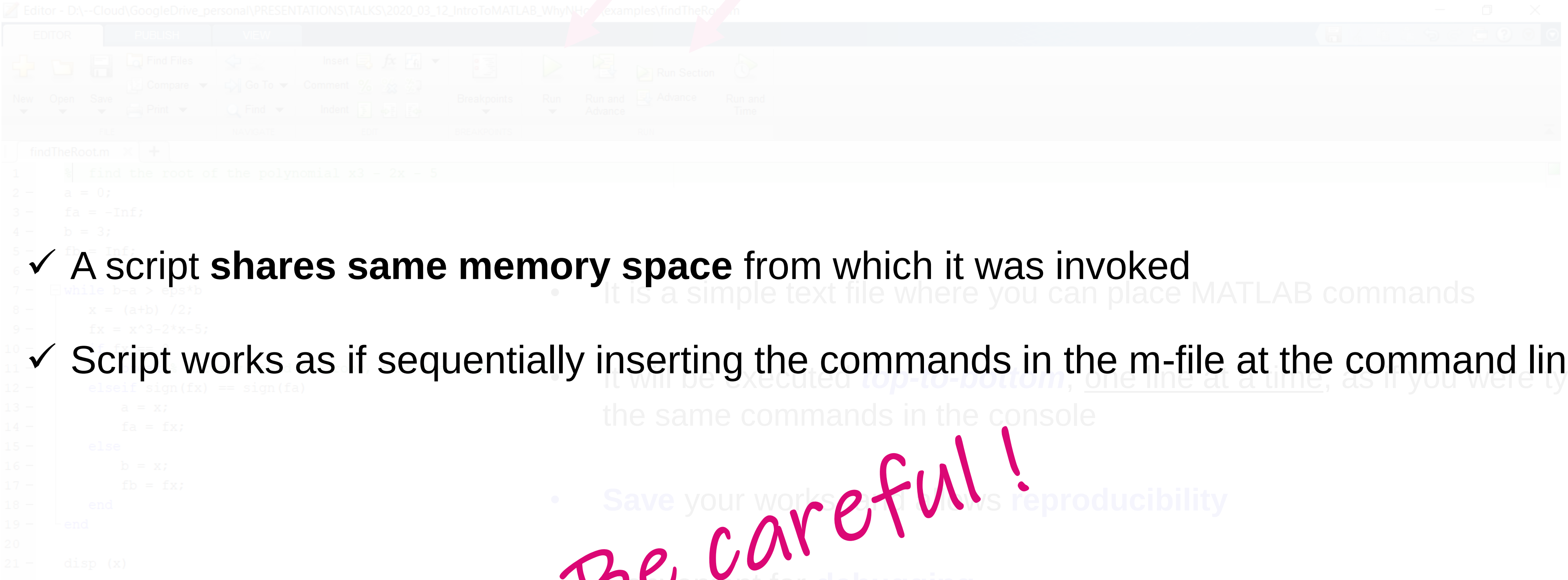
SCRIPT M-FILE



- It is a simple text file where you can place MATLAB commands
- It will be executed ***top-to-bottom***, one line at a time, as if you were typing the same commands in the console
- Run directly (even portion of it, up to a single line): **no need to be compiled**
- **Save** your works, and allows **reproducibility**

MATLAB’s EDITOR – M-file

SCRIPT M-FILE



- ✓ A script **shares same memory space** from which it was invoked
- ✓ Script works as if sequentially inserting the commands in the m-file at the command line

Be careful !

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MATLAB’s EDITOR – M-file

FUNCTION M-FILE

If you use a piece of code often, it is better to write it as a separate **function**.

The m-file begins with the keyword “function”.

The **output argument(s)** are in brackets [ ].

The **input argument(s)** are in parentheses ( ).

```
function [ output_arg ] = compute_square( input_arg )

output_arg=input_arg.^2;

end
```

The file ends with the keyword “end”.

The **name** of the function and of the file should be the **same**!

Save this as m-file: compute_square.m

MATLAB's EDITOR – M-file

FUNCTION M-FILE

✓ Once we save the function m-file, it may be called from a script or another function:

```
>> a = [1,2,3];
>> b = compute_square(a)
>> disp(b)
       1      4      9
```

✓ **All parameters** defined and used within a function **reside in function's own workspace** and are **deleted upon exiting the function**.

Good to keep in mind!

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MATLAB’s EDITOR – M-file

SCRIPT OR FUNCTION M-FILE?

Scripts

Pros:

- **convenient**; script’s variables are in same workspace as caller’s

Cons:

- **slow**; script commands loaded and interpreted each time used
- risks of variable **name conflicts** inside & outside of script

Functions

Pros:

- Scope of function’s **variables** is **confined to within function**.
- **Easier debugging** of input and outputs
- Compiled the first time it is used; it **runs faster subsequent times**.
- Easily be **re-usable** in another project.
- **Auto cleaning** of temporary variables.

Cons:

- **I/O are highly regulated**, if the function requires many pre-defined variables, it is cumbersome to pass in and out of the function – a script m-file is more convenient

Tip:

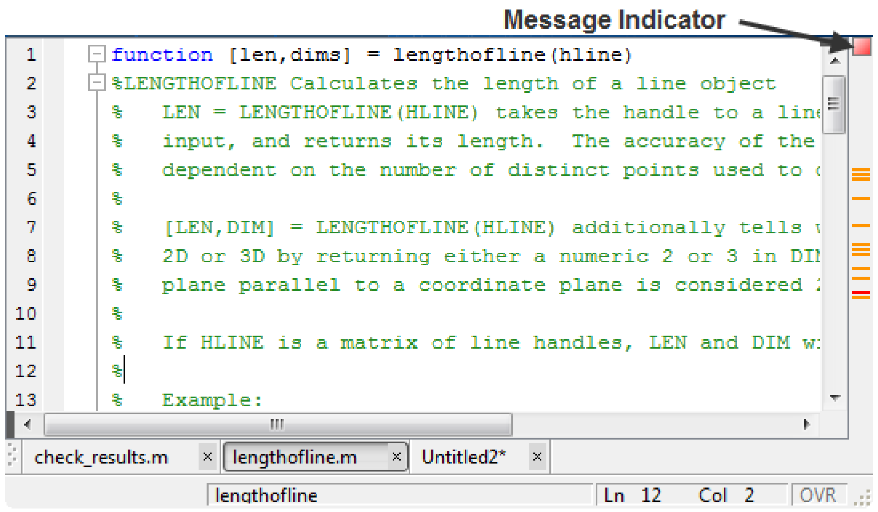
Use a script as your ‘main’ file, and refactor as much code as possible into as small as possible functions

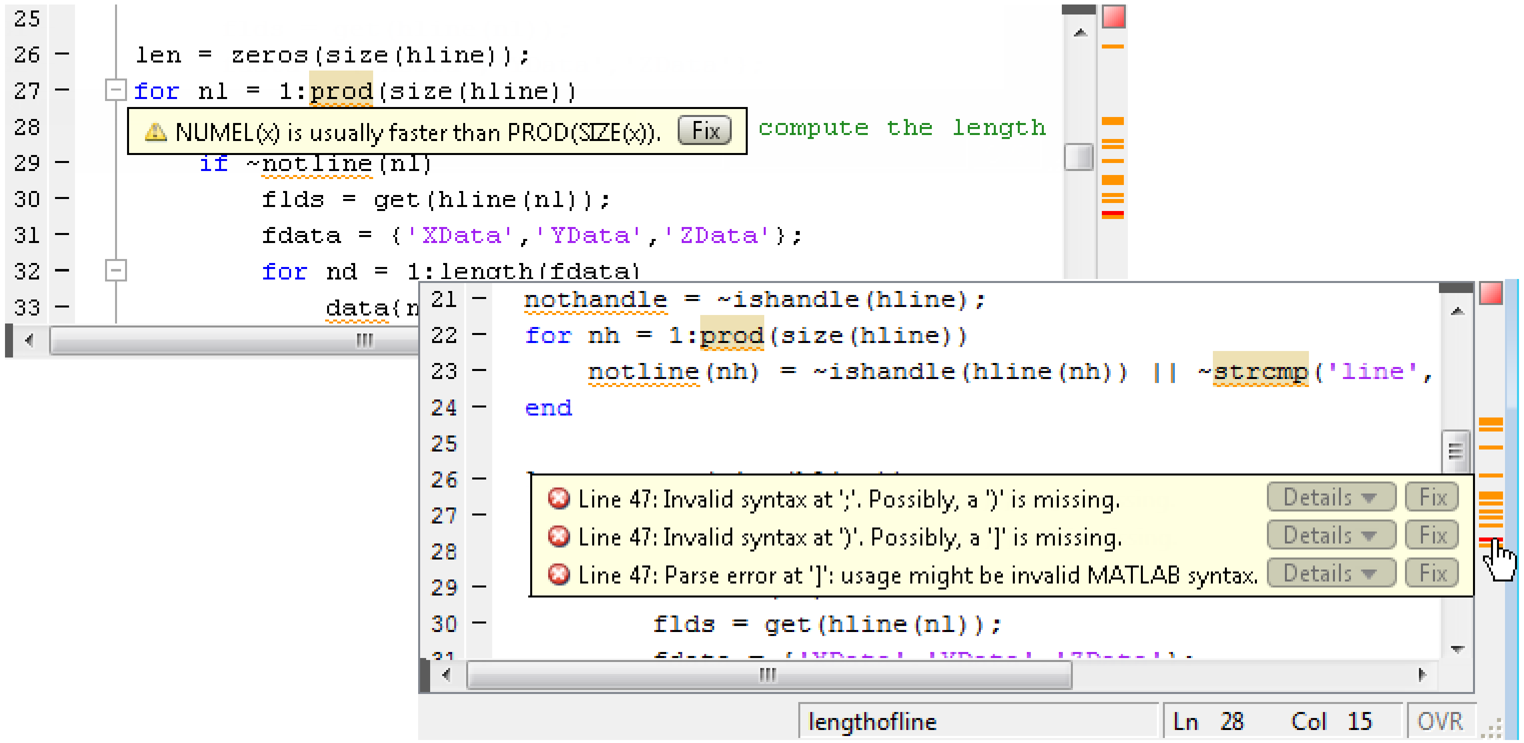
MATLAB's EDITOR – Standard editor

TIPS AND TRICKS

Automatic code checking and programming tips

You can view **warning and error messages about your code**, and modify your file based on the messages. The **messages update automatically and continuously** so you can see if your changes addressed the issues noted in the messages.



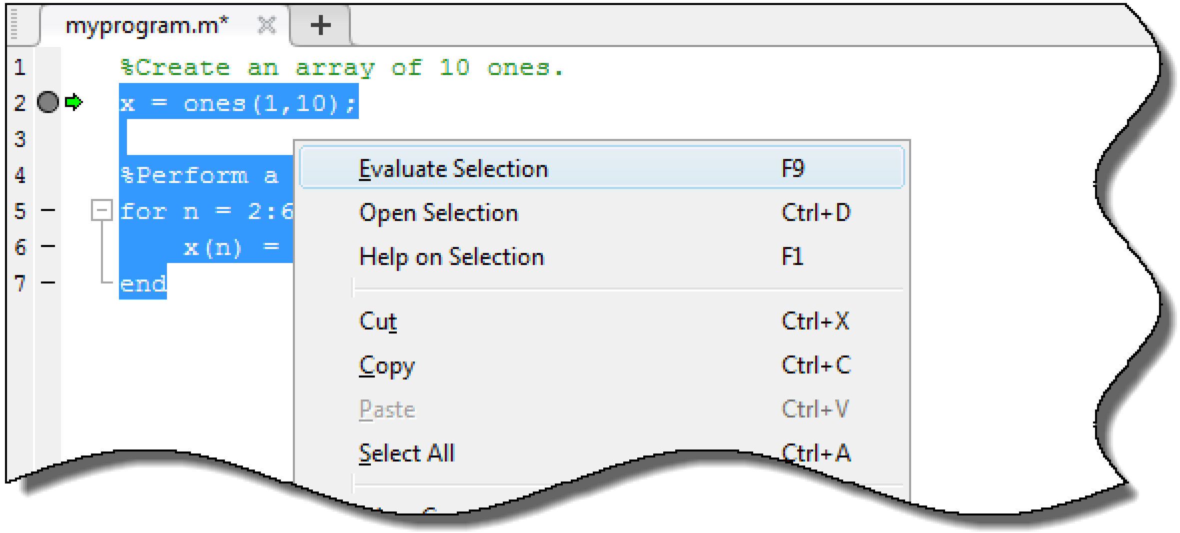


MATLAB's EDITOR – Standard editor

TIPS AND TRICKS

Interactive debugging

To run piece of code: Highlight it & press F9:



MATLAB’s EDITOR – Standard editor

TIPS AND TRICKS

‘PROPER’ debugging functionalities

1. **Set breakpoints** to pause the execution of a MATLAB file so you can examine the value or variables where you think a problem could be.
2. **Run the file.**
3. MATLAB **pauses at the first breakpoint** in the program.
4. While your code is paused, you can **view or change the values of variables**, or you can **modify the code**.
5. Press **Continue** to run the next line of code.

myprogram.m

```
%Create an array of 10 ones.
x = ones(1,10);

%Perform a calculation on items 2-6 in the array
for n = 2:6
    x(n) = 2 * x(n-1);
end
```

```
% Create an array of 10 ones.
x = ones(1,10);
```

MATLAB's EDITOR – Standard editor

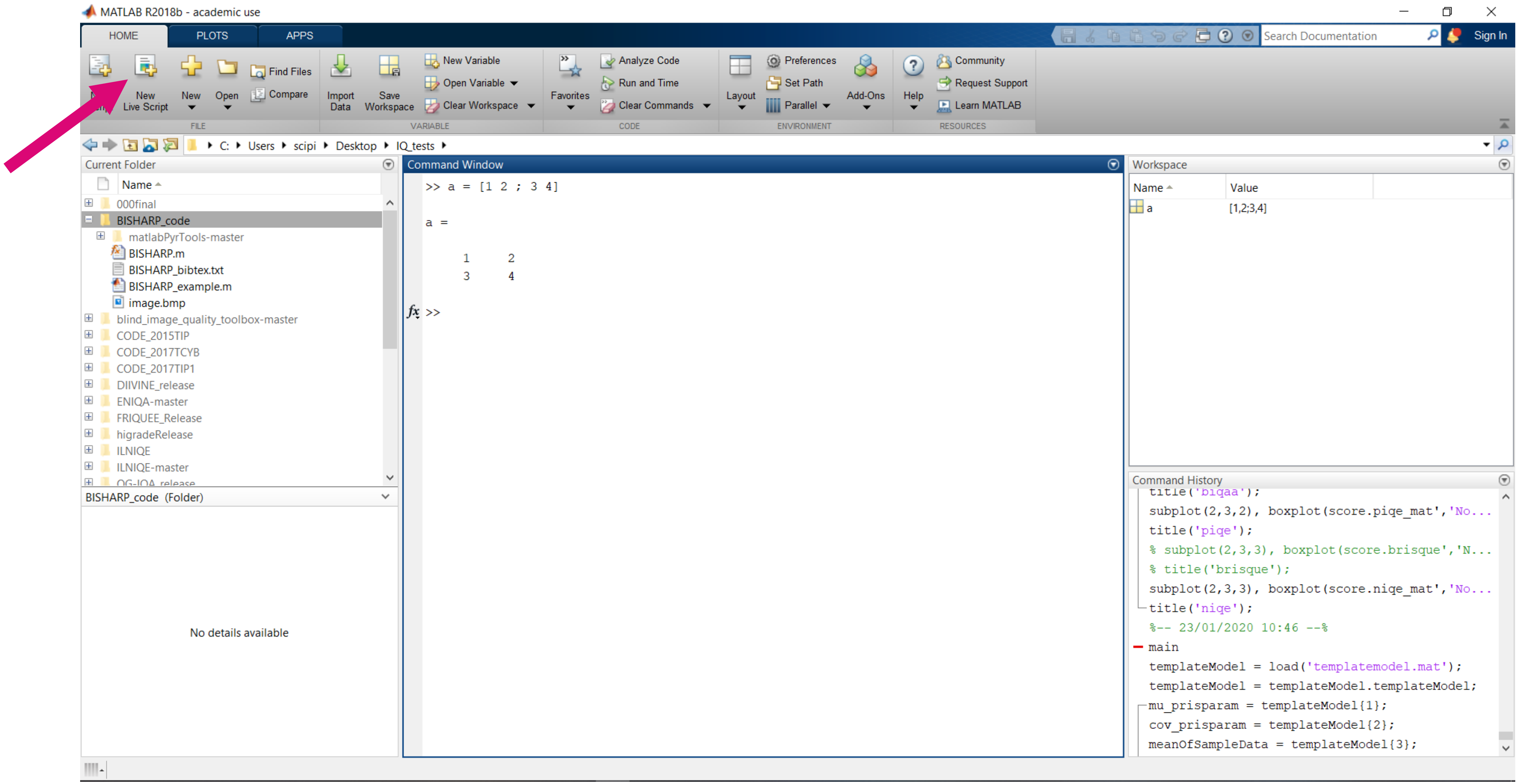
TIPS AND TRICKS

'Use "cell mode" to improve code readability!

- Inserting **%%** at the beginning of a line creates a cell, which is a block of code, within a script or a function
- If you execute the whole file, cells will be ignored (they are NOT breakpoint)
- But you can decide to evaluate just a single cell, and then jump to the next one (like F9 to evaluate a single line, but on steroids!)

```
%%%%CREATE A PATCH OBJECT WITH DESIRED VERTICES & FACES

%%
clf; cameratoolbar; axis equal off;
P_lh=patch('Faces',faces_lh_red,'Vertices',vertices_lh_red);

set(P_lh,'EdgeColor','black','FaceColor','green');

set(P_lh,'Marker','*');

%%
```

MATLAB’s Graphical User Interface (GUI)



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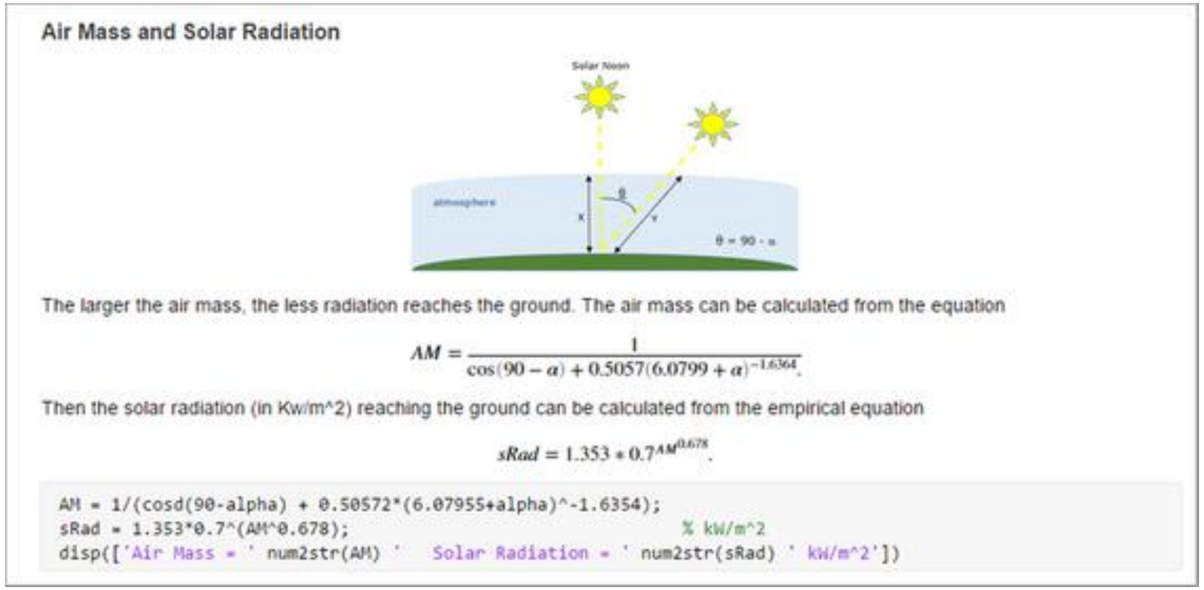
MATLAB’s EDITOR – Live editor

MATLAB live scripts and live functions are **interactive documents** that combine MATLAB code with formatted text, equations, and images in a single environment called the Live Editor. In addition, live scripts **store and display output alongside the code that creates it**.



Live scripts can be exported to **PDF, Microsoft® Word, HTML, or LaTeX.**

MATLAB's EDITOR – Live editor

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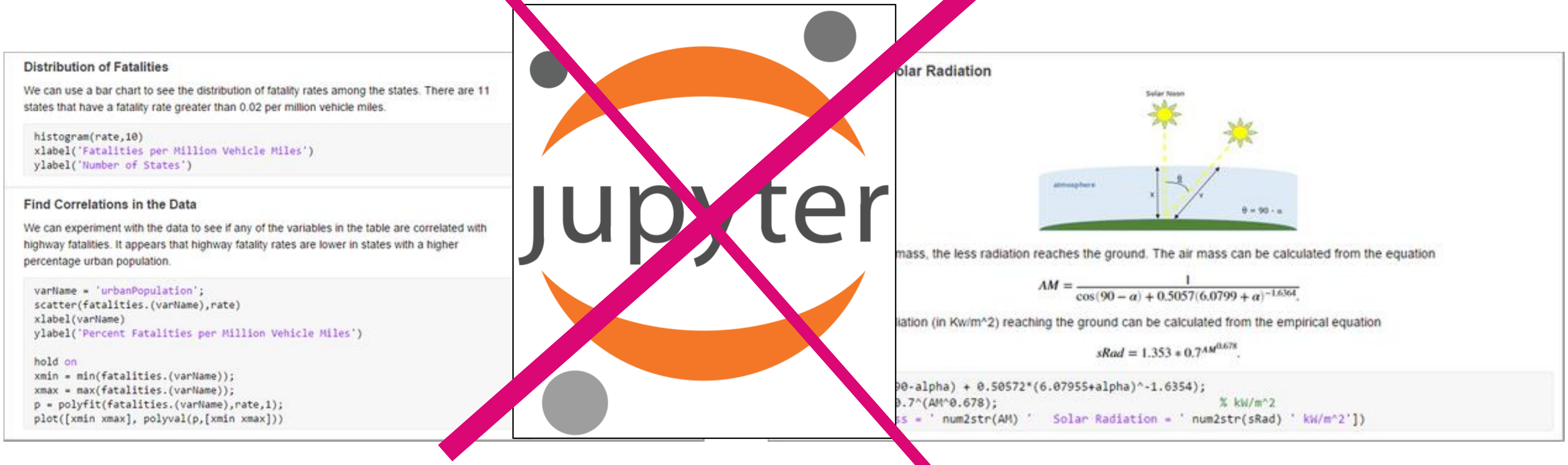

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MATLAB Graphics

PLOTTING CURVES

This is an example of how to create an line plot with legend in MATLAB®.

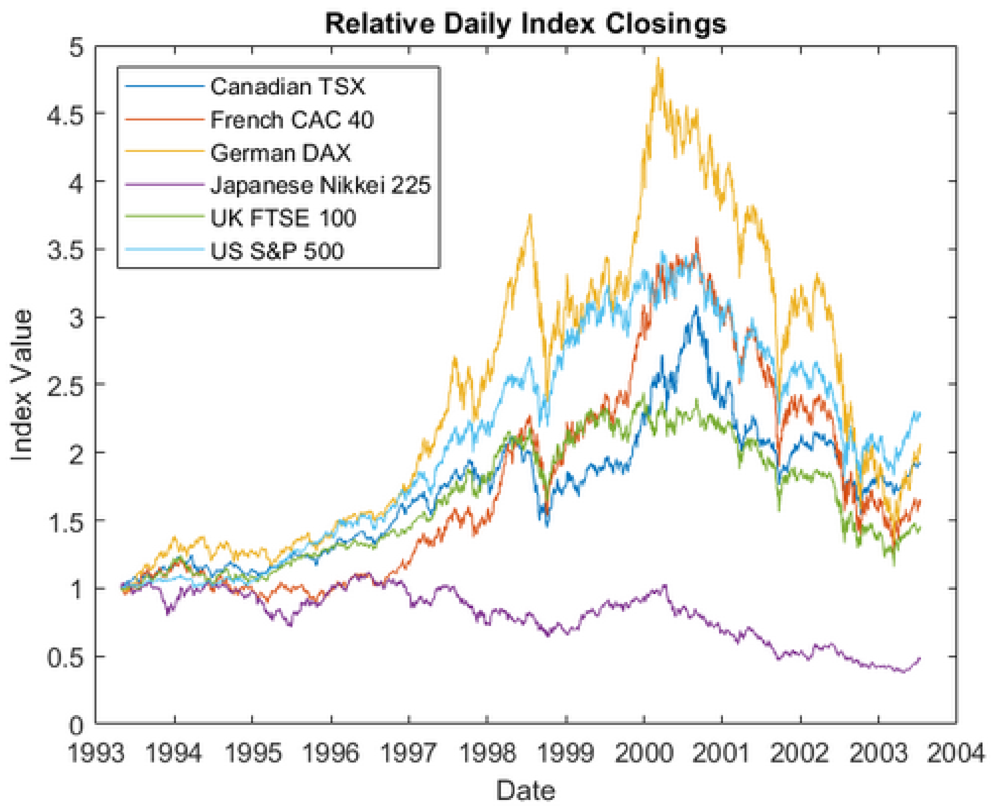
```
% Load data for the stock indices
load IndexData dates values series

% Plot the stock index values versus time
figure
plot(dates, values)

% Use dateticks for the x axis
datetick('x')

% Add title and axis labels
xlabel('Date')
ylabel('Index Value')
title('Relative Daily Index Closings')

% Add a legend in the top, left corner
legend(series, 'Location', 'NorthWest')
```



MATLAB Graphics

PLOTTING CURVES

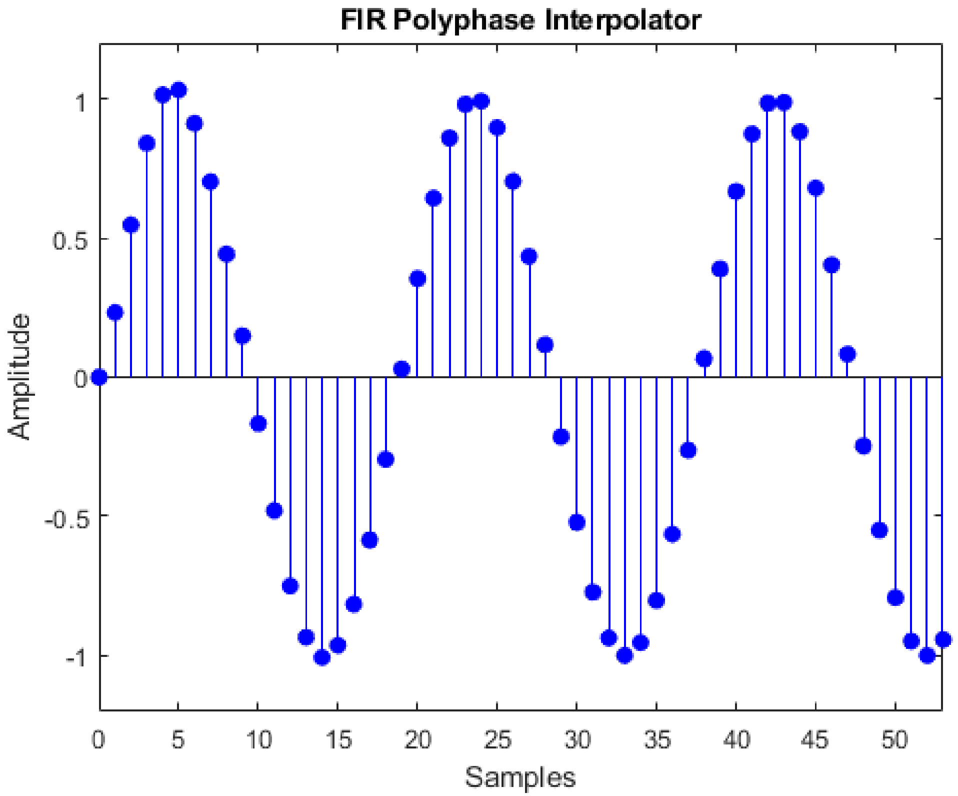
This is an example of how to create a simple stem plot in MATLAB®.

```
% Load amplitude data
load amplitudeData sample amplitude

% Create a stem plot using the stem function
figure
stem(sample, amplitude, 'filled', 'b')

% Adjust the axis limits
axis([0 53 -1.2 1.2])

% Add title and axis labels
title('FIR Polyphase Interpolator')
xlabel('Samples')
ylabel('Amplitude')
```



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MATLAB Graphics

PLOTTING CURVES

This is an example of how to create a curve with lower and upper bounds in MATLAB®.

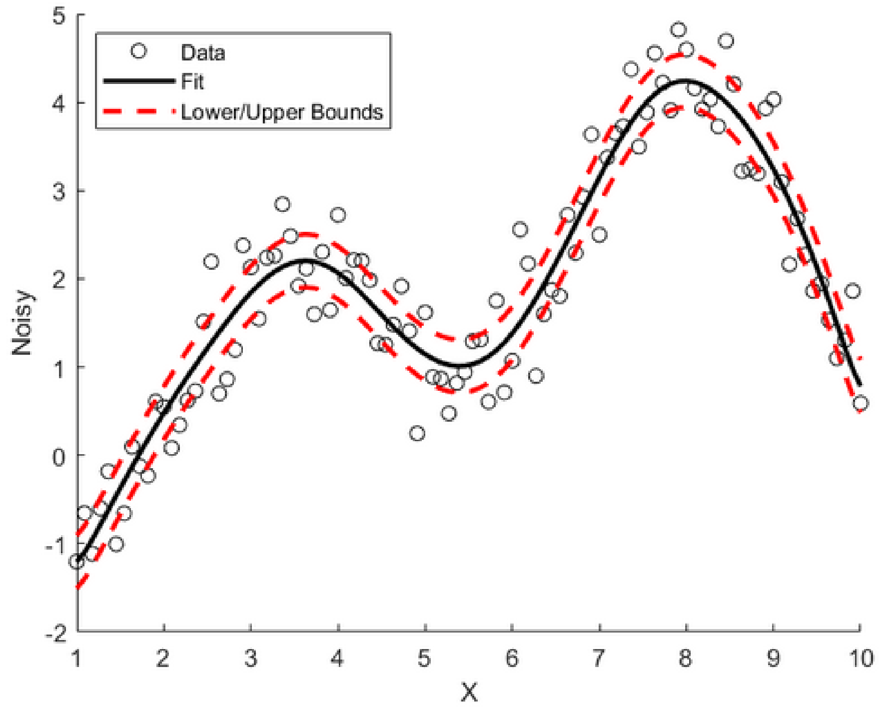
```
% Load the data for x, y, and yfit
load fitdata x y yfit

% Create a scatter plot of the original x and y data
figure
scatter(x, y, 'k')

% Plot yfit
line(x, yfit, 'Color', 'k', 'LineStyle', '-', 'LineWidth', 2)

% Plot upper and lower bounds, calculated as 0.3 from yfit
line(x, yfit + 0.3, 'Color', 'r', 'LineStyle', '--', 'LineWidth', 2)
line(x, yfit - 0.3, 'Color', 'r', 'LineStyle', '--', 'LineWidth', 2)

% Add a legend and axis labels
legend('Data', 'Fit', 'Lower/Upper Bounds', 'Location', 'NorthWest')
xlabel('X')
ylabel('Noisy')
```



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MATLAB Graphics

PLOTTING CURVES

This is an example of how to create a plot with two y axes in MATLAB®.

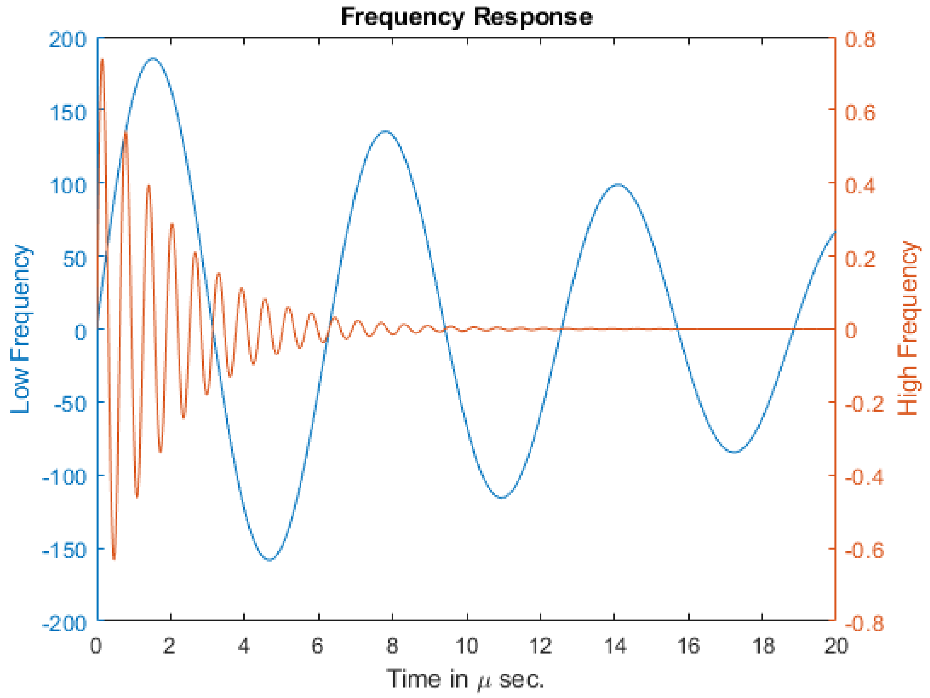
```
% Check version
if verLessThan('matlab','9.0')
    error(['yyaxis is available in R2016a or newer. ', ...
        'For older releases, use plotyy instead.'])
end

% Create some data for the two curves to be plotted
x  = 0:0.01:20;
y1 = 200*exp(-0.05*x).*sin(x);
y2 = 0.8*exp(-0.5*x).*sin(10*x);

% Create a plot with 2 y axes using the yyaxis function
figure
yyaxis left
plot(x, y1)
ylabel('Low Frequency')

yyaxis right
plot(x, y2)
ylabel('High Frequency')

% Add title and x axis label
xlabel('Time in \mu sec.')
title('Frequency Response')
```



MATLAB Graphics

PLOTTING 3D DATASETS

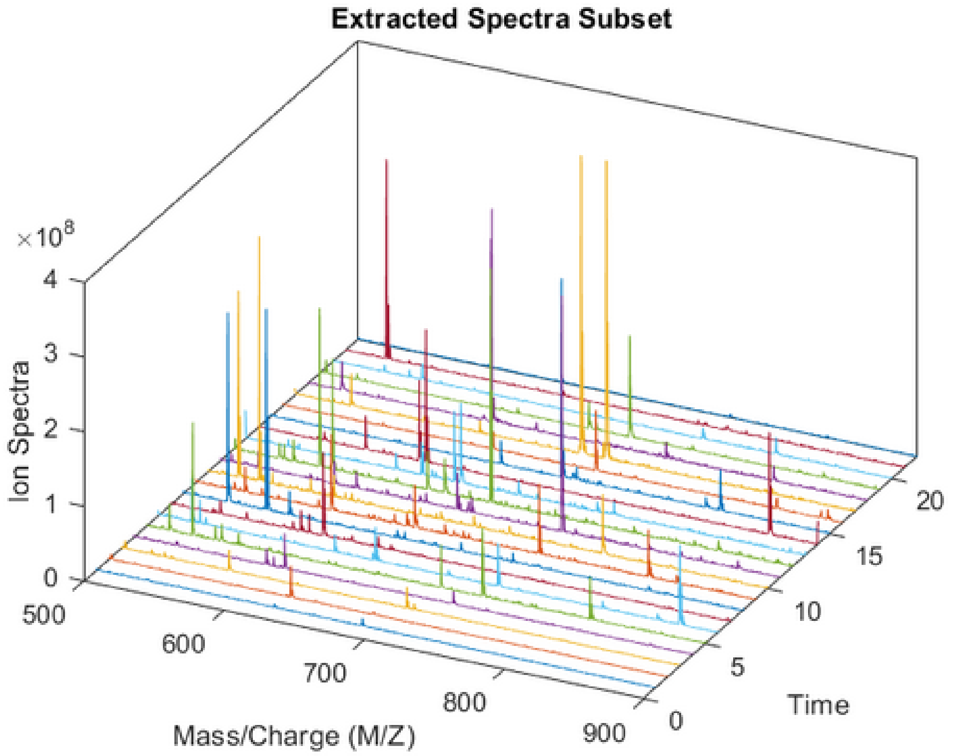
This is an example of how to create a 3D plot in MATLAB®.

```
% Load the spectra data
load spectraData masscharge time spectra

% Create the 3D plot
figure
plot3(masscharge, time, spectra)
box on

% Set the viewing angle and the axis limits
view(26, 42)
axis([500 900 0 22 0 4e8])

% Add title and axis labels
xlabel('Mass/Charge (M/Z)')
ylabel('Time')
zlabel('Ion Spectra')
title('Extracted Spectra Subset')
```



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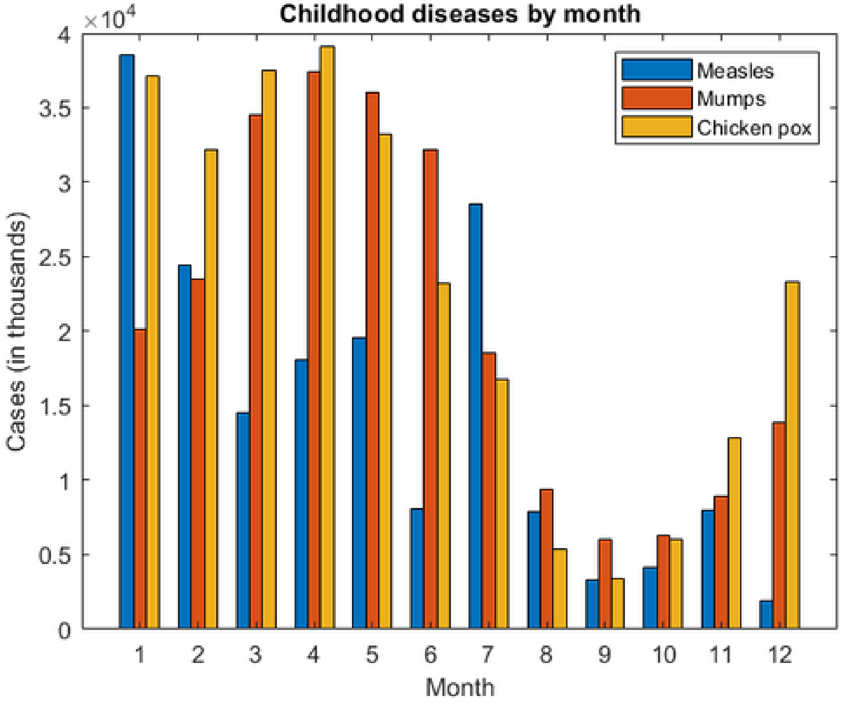
MATLAB Graphics

PLOTTING DATA / HISTOGRAMS / BARPLOTS

This is an example of how to create a vertical bar chart in MATLAB®.

```
% Create data for childhood disease cases
measles = [38556 24472 14556 18060 19549 8122 28541 7880 3283 4135 7953 1884];
mumps = [20178 23536 34561 37395 36072 32237 18597 9408 6005 6268 8963 13882];
chickenPox = [37140 32169 37533 39103 33244 23269 16737 5411 3435 6052 12825 23332];

% Create a vertical bar chart using the bar function
figure
bar(1:12, [measles' mumps' chickenPox'], 1)

% Set the axis limits
axis([0 13 0 40000])
set(gca, 'XTick', 1:12)

% Add title and axis labels
title('Childhood diseases by month')
xlabel('Month')
ylabel('Cases (in thousands)')

% Add a legend
legend('Measles', 'Mumps', 'Chicken pox')
```

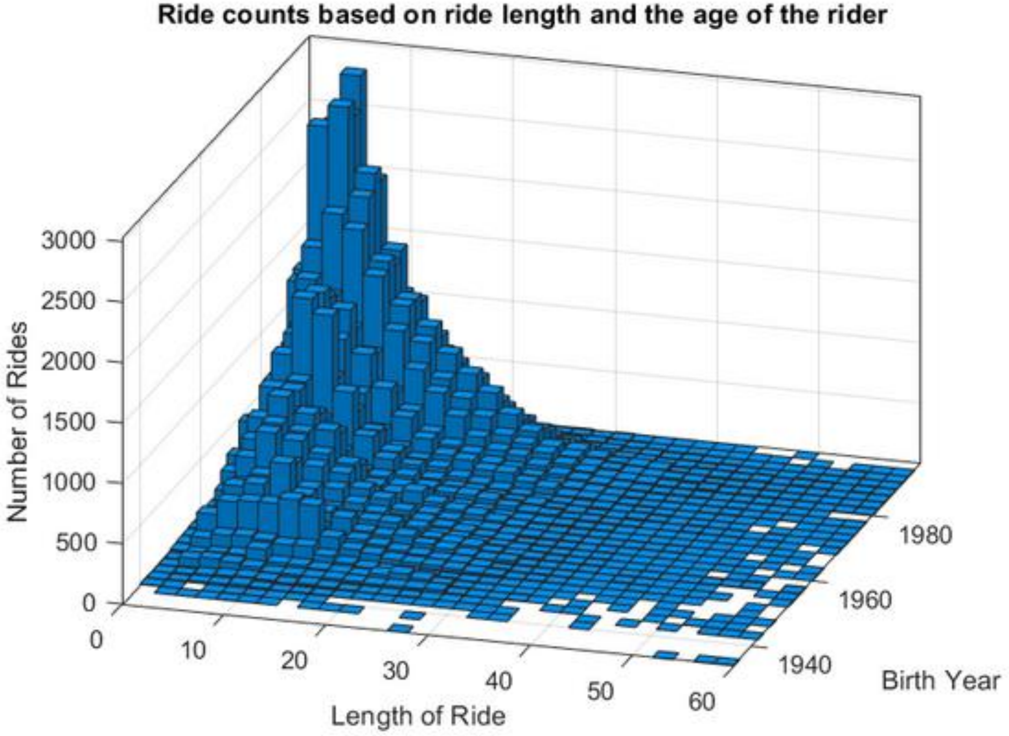


MATLAB Graphics

PLOTTING DATA / HISTOGRAMS / BARPLOTS

This is an example of how to create a bivariate histogram in MATLAB®.

```
% Check version
if verLessThan('matlab','8.6')
    error('histogram2 is available in R2015b or newer.')
end

% Load ride data from Boston's bike sharing program
load rideData rideData

% Create bivariate histogram plot using the histogram2 function
histogram2(rideData.Duration, rideData.birth_date, 'BinWidth', [2 2])
xlabel('Length of Ride')
ylabel('Birth Year')
zlabel('Number of Rides')
title('Ride counts based on ride length and the age of the rider')

% Adjust view
view(17,30)
```

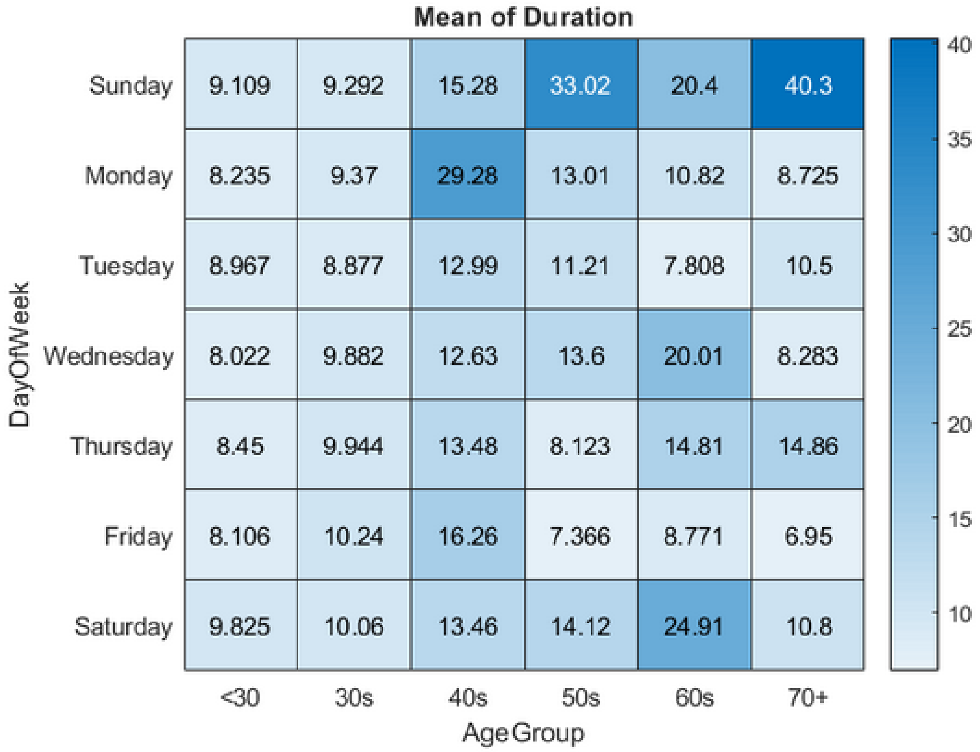


MATLAB Graphics

SHOWING TABULAR DATA AS HEATMAPS

This is an example of how to create a heatmap chart in MATLAB®.

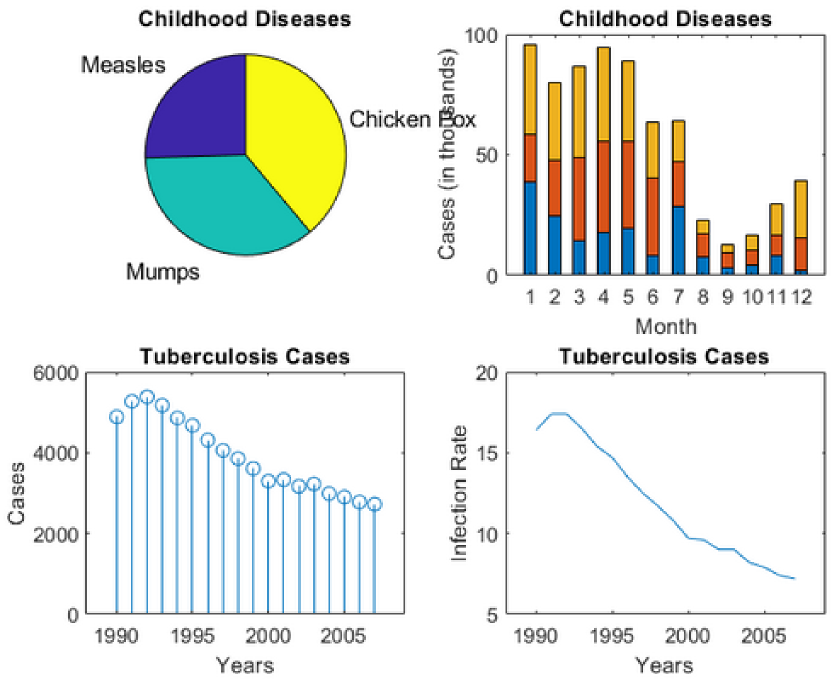
```
% Check version
if verLessThan('matlab','9.2')
    error('heatmap is available in R2017a or newer.')
end

% Load ride data from Boston's bike sharing program
load CambridgeData cambridge

% Create a heatmap of DayOfWeek vs. AgeGroup, with color representing count
hm = heatmap(cambridge,'AgeGroup','DayOfWeek');

% Change the color to represent average Duration
hm.ColorVariable = 'Duration';
hm.ColorMethod = 'mean';
```



MATLAB Graphics

ASSEMBLING COMPLEX FIGURES USING SUBPLOTS

```
% Create the pie chart in position 1 of a 2x2 grid
figure
subplot(2, 2, 1)
pie([sum(measles) sum(mumps) sum(chickenPox)], {'Measles', 'Mumps', 'Chicken Po
title('Childhood Diseases')

% Create the bar chart in position 2 of a 2x2 grid
subplot(2, 2, 2)
bar(1:12, [measles/1000 mumps/1000 chickenPox/1000], 0.5, 'stack')
xlabel('Month')
ylabel('Cases (in thousands)')
title('Childhood Diseases')
axis([0 13 0 100])
set(gca, 'XTick', 1:12)

% Create the stem chart in position 3 of a 2x2 grid
subplot(2, 2, 3)
stem(years, cases)
xlabel('Years')
ylabel('Cases')
title('Tuberculosis Cases')
axis([1988 2009 0 6000])

% Create the line plot in position 4 of a 2x2 grid
subplot(2, 2, 4)
plot(years, rate)
xlabel('Years')
ylabel('Infection Rate')
title('Tuberculosis Cases')
axis([1988 2009 5 20])
```

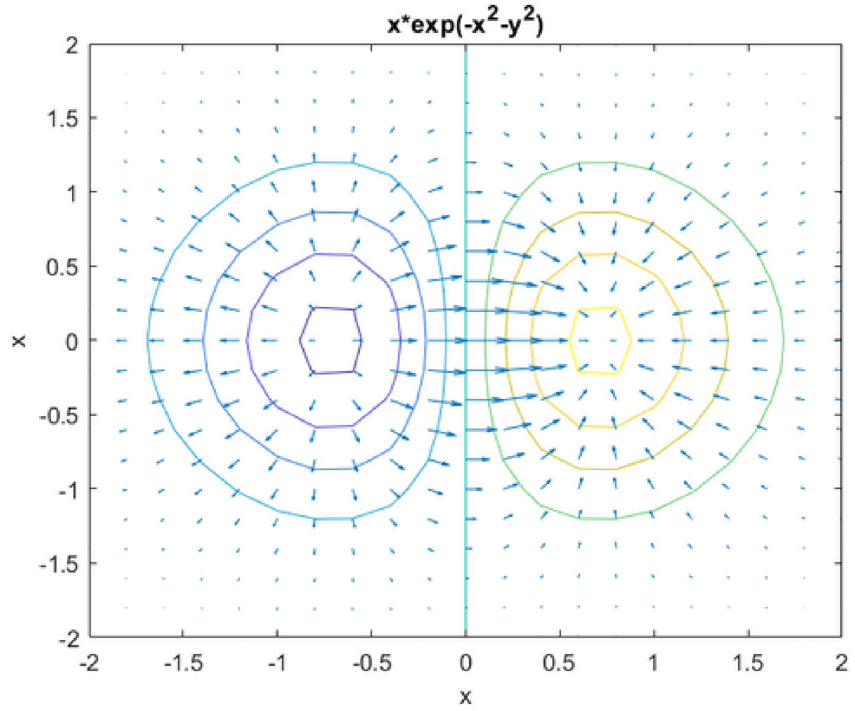


MATLAB Graphics

VISUALIZING 2D/3D VECTOR FIELDS

This is an example of how to create a 2D quiver plot in MATLAB®.

```
% Create a grid of x and y points
[x, y] = meshgrid(-2:.2:2);

% Create the function z(x,y) and its gradient
z = x.*exp(-x.^2 - y.^2);
[dx, dy] = gradient(z, .2, .2);

% Create a contour plot of x, y, and z using the contour function
figure
contour(x,y,z)
hold on

% Create a quiver plot of x, y, and the gradients using the quiver function
q = quiver(x, y, dx, dy);

% Set the axis limits
xlim([-2 2])
ylim([-2 2])

% Add title and axis labels
title('x*exp(-x^2-y^2)')
xlabel('x')
ylabel('x')
```



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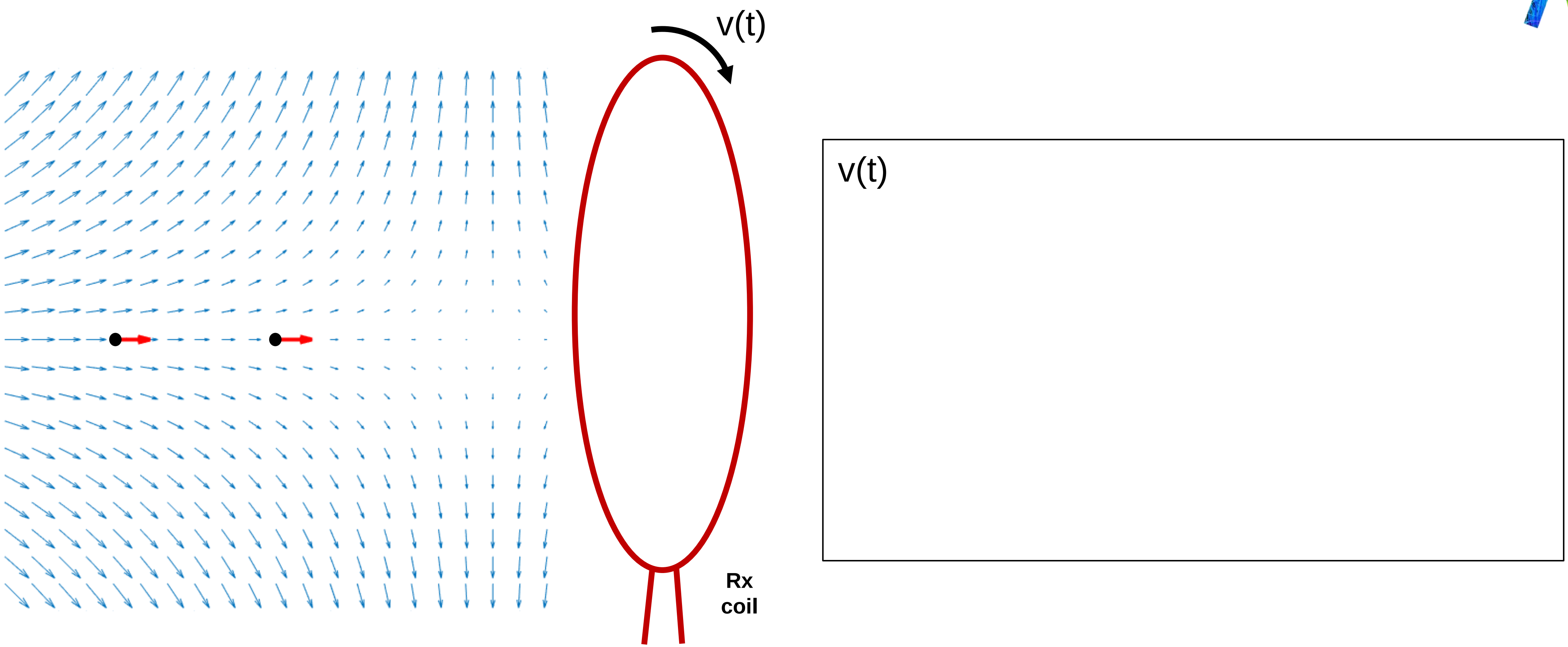
MATLAB Graphics

VISUALIZING 2D/3D VECTOR FIELDS



Credits to Melissa Haskell

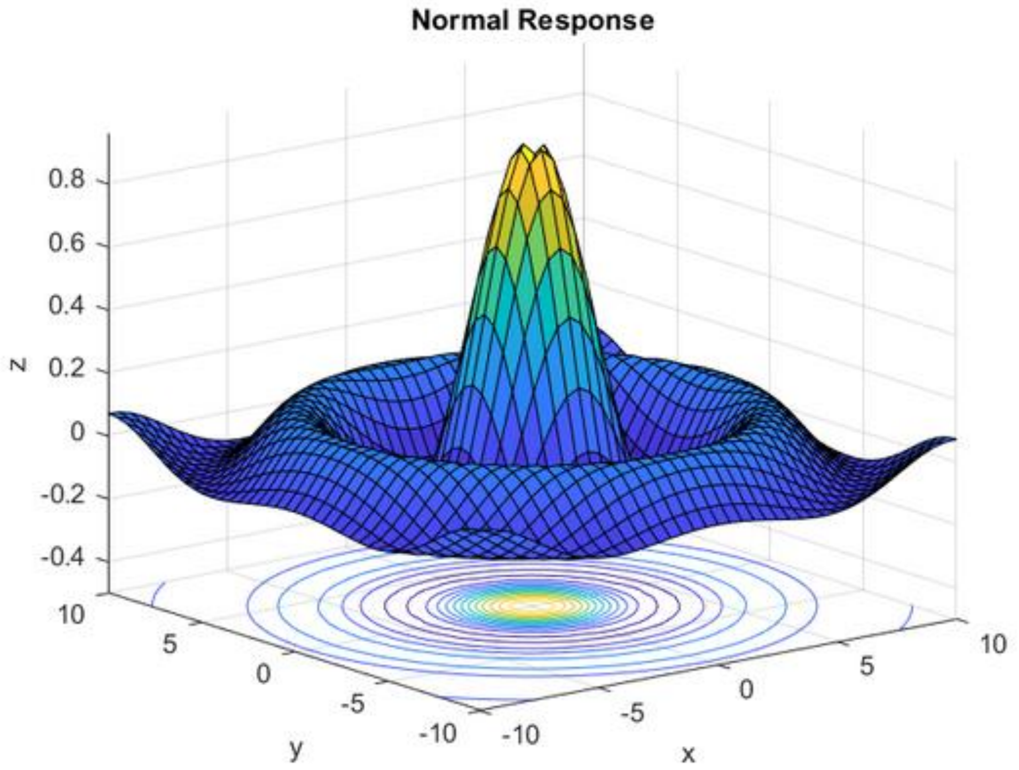
«Introduction to MATLAB», Why & How Series 2019

MATLAB Graphics

SURFACE RENDERING WITH MATLAB

This is an example of how to create a surface contour plot in MATLAB®.

```
% Create a grid of x and y data
y = -10:0.5:10;
x = -10:0.5:10;
[X, Y] = meshgrid(x, y);

% Create the function values for Z = f(X,Y)
Z = sin(sqrt(X.^2+Y.^2)) ./ sqrt(X.^2+Y.^2);

% Create a surface contour plor using the surfc function
figure
surfc(X, Y, Z)

% Adjust the view angle
view(-38, 18)

% Add title and axis labels
title('Normal Response')
xlabel('x')
ylabel('y')
zlabel('z')
```

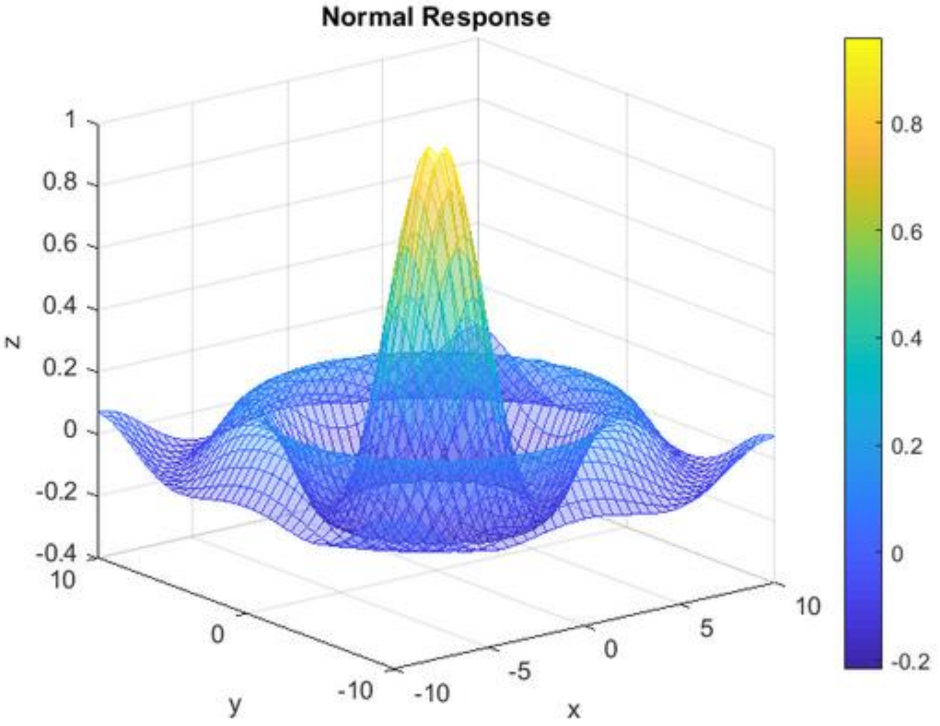


MATLAB Graphics

SURFACE RENDERING WITH MATLAB

This is an example of how to create a 3D mesh plot in MATLAB®.

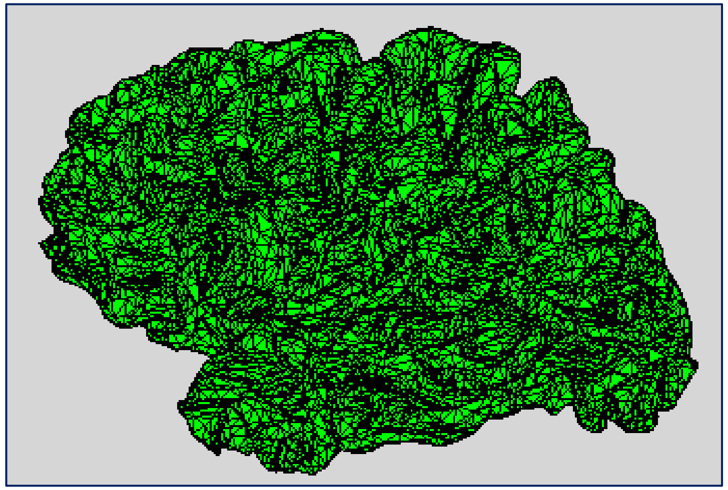
```
% Create a grid of x and y data
y = -10:0.5:10;
x = -10:0.5:10;
[X, Y] = meshgrid(x, y);

% Create the function values for Z = f(X,Y)
Z = sin(sqrt(X.^2+Y.^2)) ./ sqrt(X.^2+Y.^2);

% Create a surface contour plor using the mesh function
figure
s = mesh(X, Y, Z,'FaceAlpha','0.3');

% Adjust the view angle
view(-38, 18)

% Add title and axis labels
title('Normal Response')
xlabel('x')
ylabel('y')
zlabel('z')

% Customize the plot
colorbar
s.FaceColor = 'flat';
```

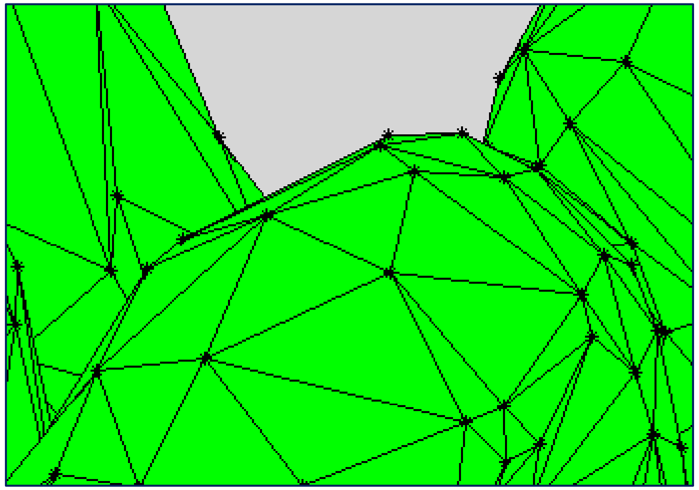


MATLAB Graphics

SURFACE RENDERING WITH MATLAB

Discrete surface consists of "**vertex points**" and "**edges**":





If you want to render your own mesh/surface in MATLAB, you need two lists of numbers:

- "**Vertices**" are the coordinates of surface points.
- "**Faces**" tell which three vertices form a given triangle.

Credits to Melissa Haskell

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MATLAB Graphics

DISPLAY IMAGES

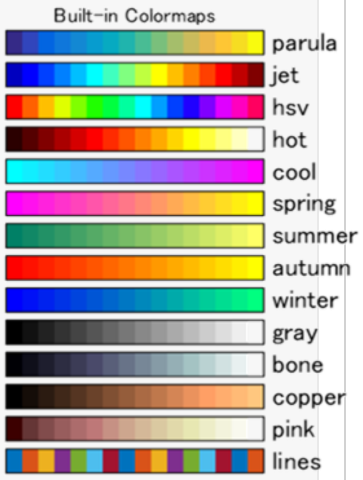
This is an example of how to display multiple images in a subplot in MATLAB®.

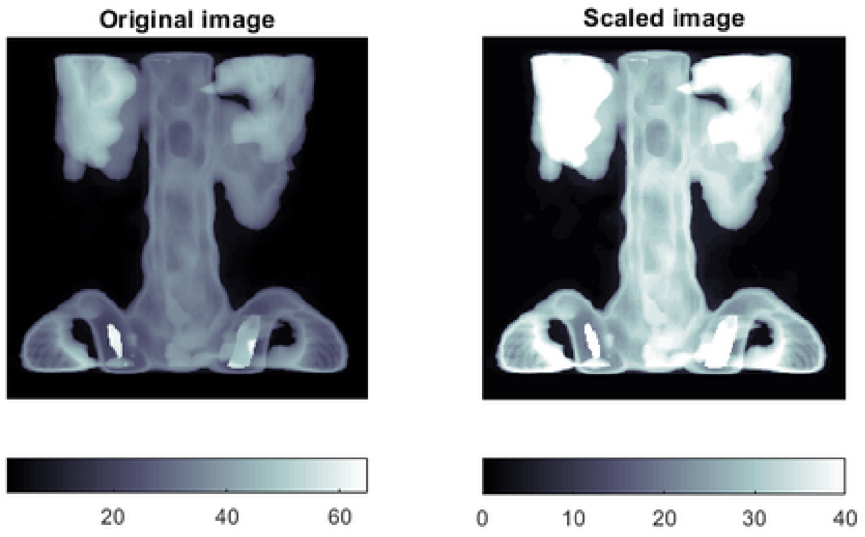
```
% Read the data for the original image
load spine X
original = X;

% Create the first image display using the image command
figure
ax(1) = subplot(1, 2, 1);
image(original)
axis square off
title('Original image')
colorbar('SouthOutside')

% Create the second image display using the imagesc
ax(2) = subplot(1, 2, 2);
imagesc(original, [0,40])
axis square off
title('Scaled image')
colorbar('SouthOutside')

colormap(ax(1),'bone')
colormap(ax(2),'bone')
```





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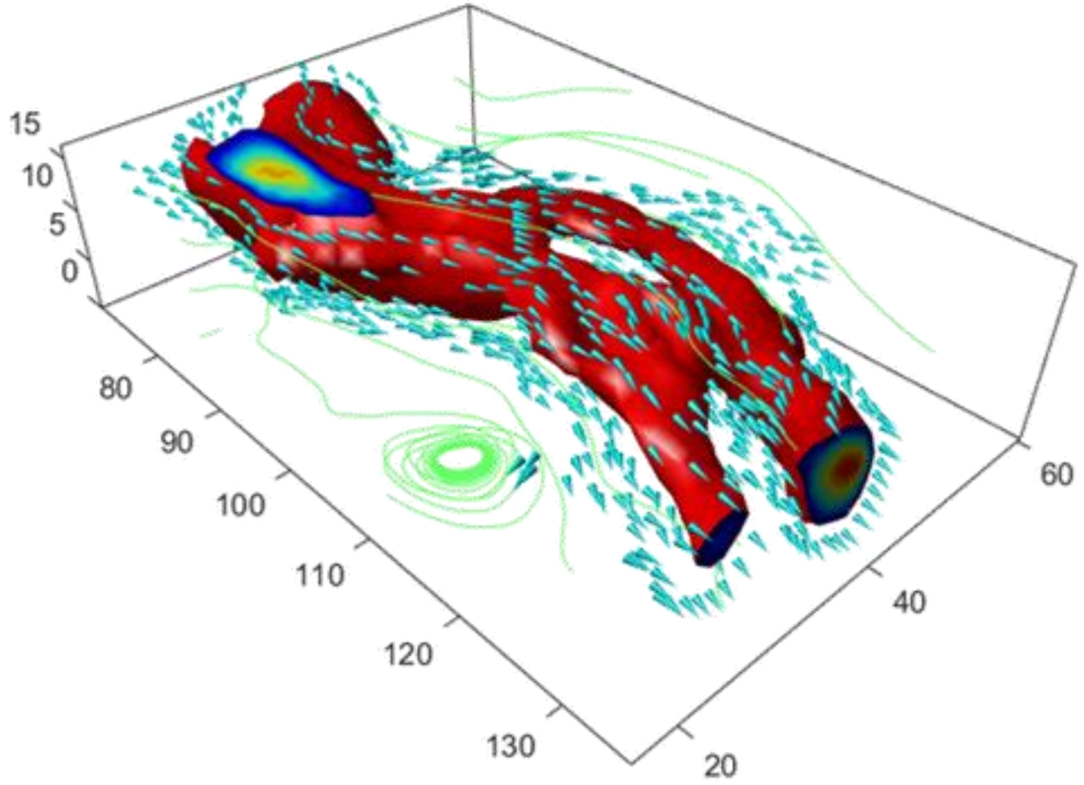
MATLAB Graphics

HOW CRAZY CAN YOU GO?

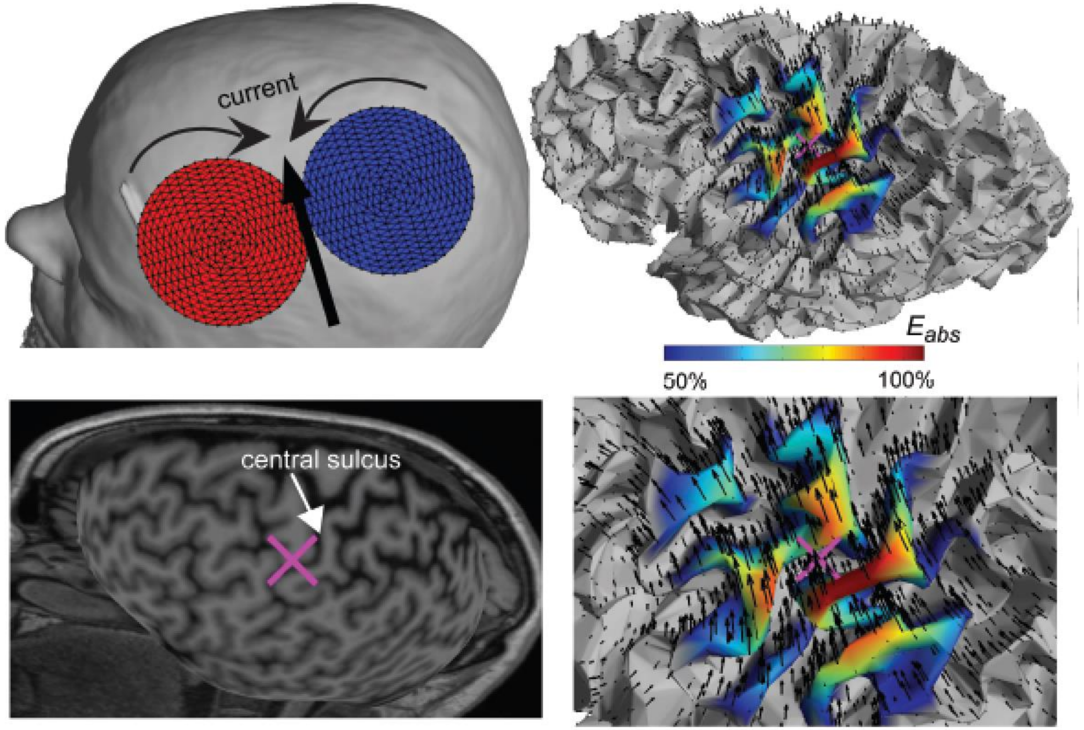
```
figure

% Create isosurface patch
p = patch(isosurface(x, y, z, spd, 40));
isonormals(x, y, z, spd, p)
set(p, 'FaceColor', 'red', 'EdgeColor', 'none')

% Create isosurface end-caps
p2 = patch(isocaps(x, y, z, spd, 40));
set(p2, 'FaceColor', 'interp', 'EdgeColor', 'none')

% Adjust aspect ratio
daspect([1 1 1])

% Downsample patch
[f, verts] = reducepatch(isosurface(x, y, z, spd, 30), .2);

% Create coneplot (velocity cone)
h = coneplot(x, y, z, u, v, w, verts(:, 1), verts(:, 2), verts(:, 3), 2);
set(h, 'FaceColor', 'cyan', 'EdgeColor', 'none')

% Create streamline
[sx, sy, sz] = meshgrid(80, 20:10:50, 0:5:15);
h2 = streamline(x, y, z, u, v, w, sx, sy, sz);
set(h2, 'Color', [.4 1 .4])

% Adjust colormap and axes settings
colormap(jet)
box on
axis tight
camproj perspective
camva(34)
campos([165 -20 65])
camtarget([100 40 -5])
camlight left
lighting gouraud
```

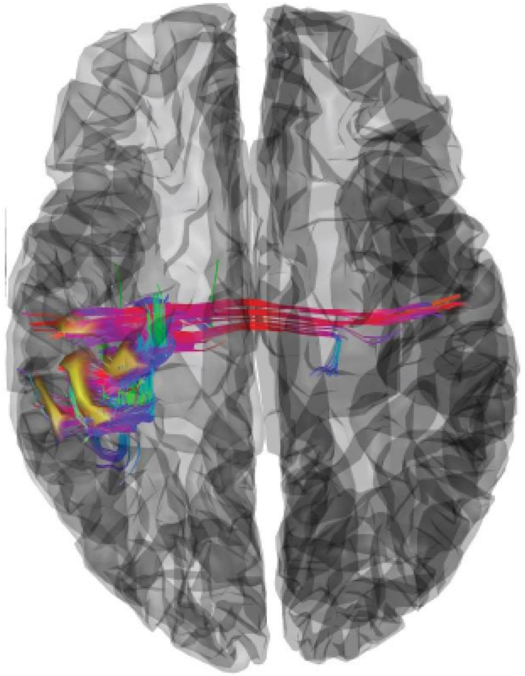
isosurface
isonormals
isocaps
coneplot
streamline
patch
reducepatch



MATLAB Graphics

HOW CRAZY CAN YOU GO?





Credits to Melissa Haskell

«Introduction to MATLAB», Why & How Series 2019

Overview

- WHAT?
- WHY?
- HOW?
  - GETTING STARTED
  - SCRIPTS, FUNCTIONS, AND THE EDITOR
  - VISUALIZATION TOOLS
- BUT … CAN I STILL USE IT, IF I DON’T KNOW HOW TO CODE?

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Overview

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MATLAB's own options

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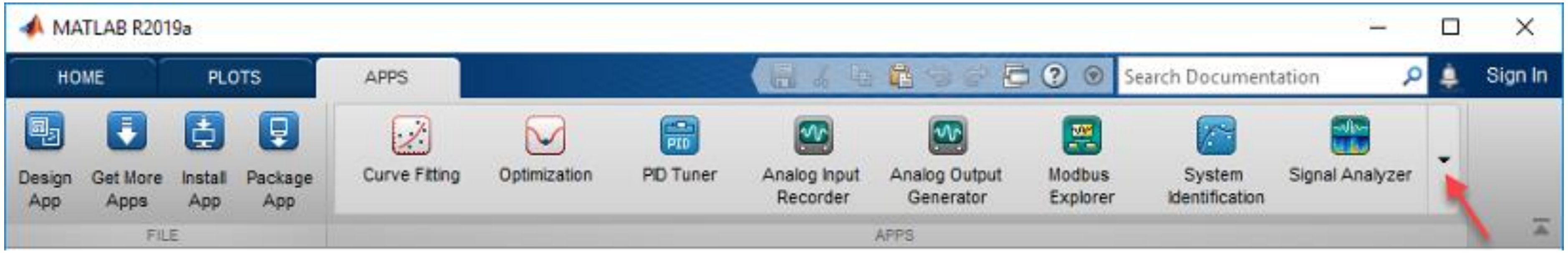
Matlab APPS

- A MATLAB app is a **self-contained MATLAB program** with a user interface that automates a task or calculation.
- **All the operations** required to complete the task (getting data into the app, performing calculations on the data, and getting results) **are performed within the app**.



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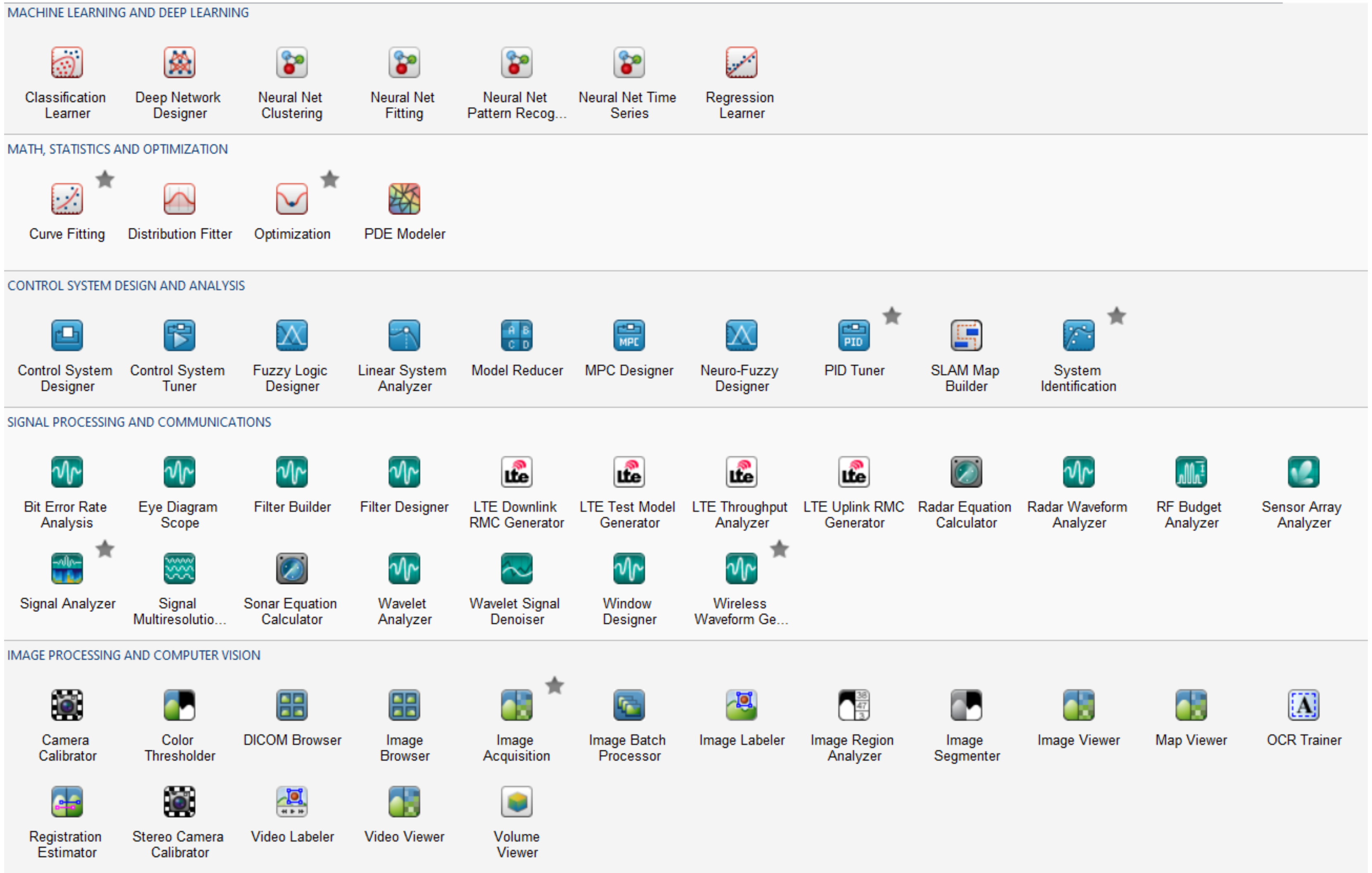
Matlab APPS



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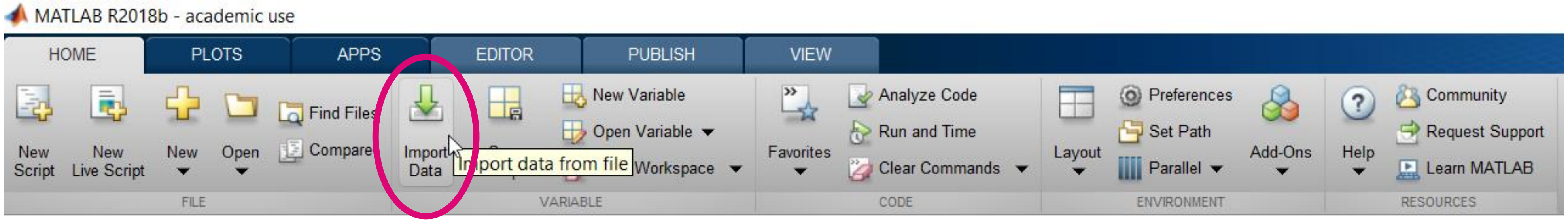
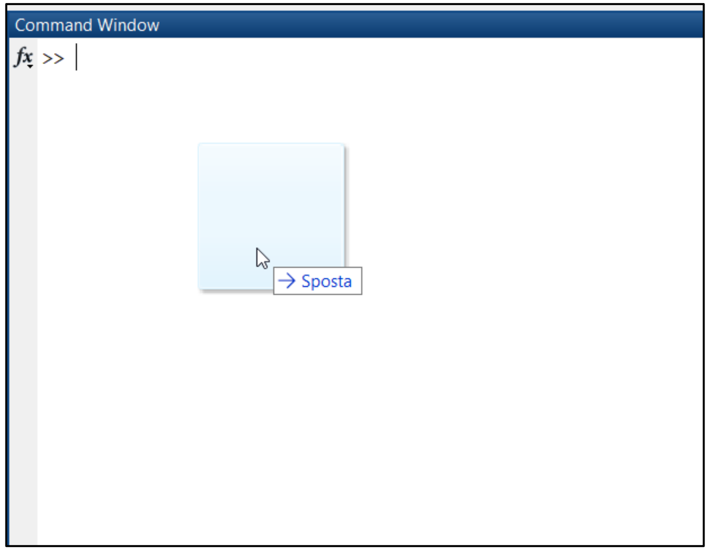
Matlab APPS

INTERACTIVE DATA IMPORT



Click 'Import Data' from the toolbar and select file, or ...

... Drag & Drop data file in Command Window



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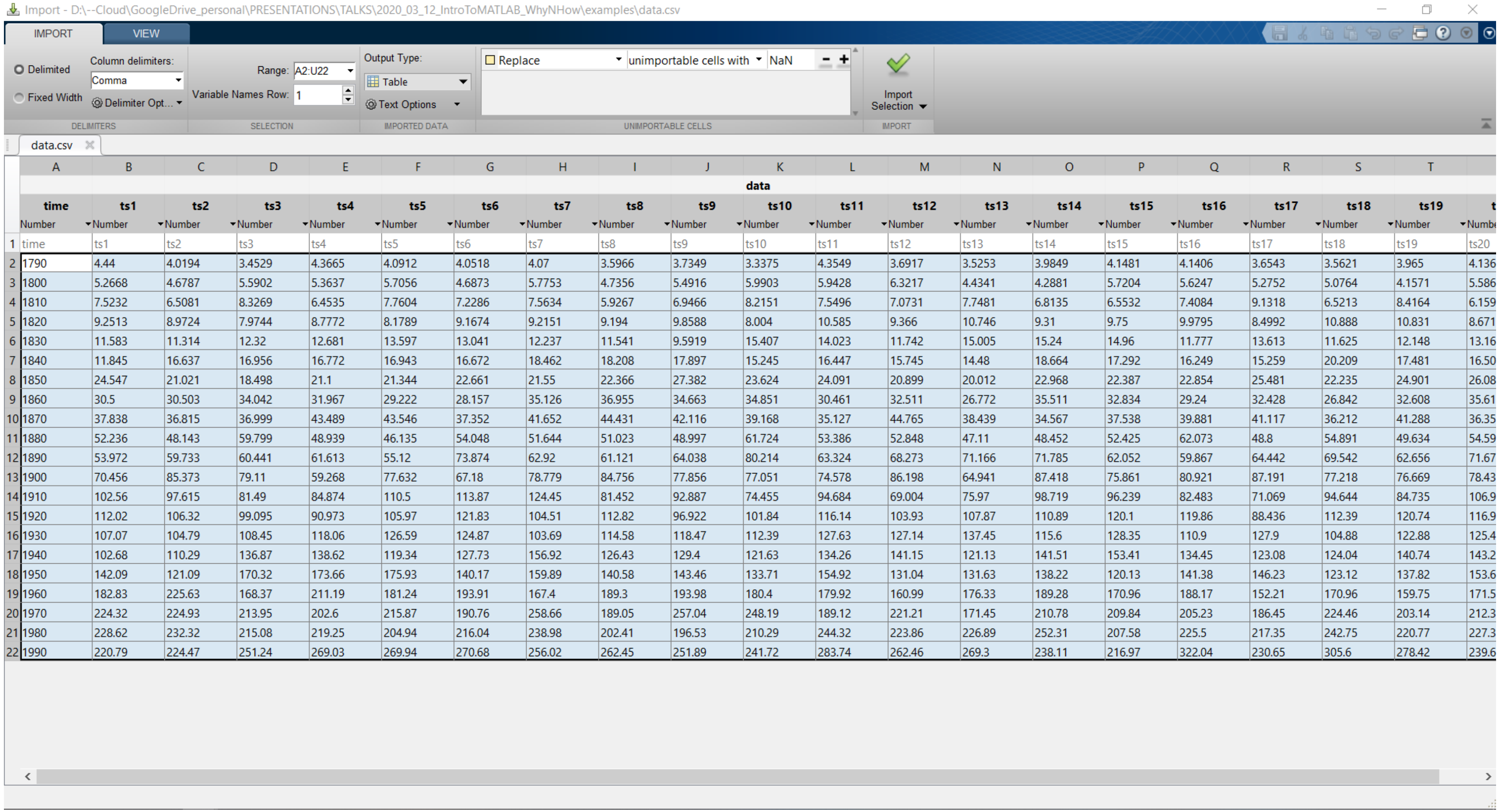
Matlab APPS

INTERACTIVE DATA IMPORT



time	ts1	ts2	ts3	ts4	ts5	ts6	ts7	ts8	ts9	ts10	ts11	ts12	ts13	ts14	ts15	ts16	ts17	ts18	ts19	t
Number	Number	Number	Number	Number	Number	Number	Number	Number	Number	Number	Number	Number	Number	Number	Number	Number	Number	Number	Number	Numbe
time	ts1	ts2	ts3	ts4	ts5	ts6	ts7	ts8	ts9	ts10	ts11	ts12	ts13	ts14	ts15	ts16	ts17	ts18	ts19	ts20
1790	4.44	4.0194	3.4529	4.3665	4.0912	4.0518	4.07	3.5966	3.7349	3.3375	4.3549	3.6917	3.5253	3.9849	4.1481	4.1406	3.6543	3.5621	3.965	4.136
1800	5.2668	4.6787	5.5902	5.3637	5.7056	4.6873	5.7753	4.7356	5.4916	5.9903	5.9428	6.3217	4.4341	4.2881	5.7204	5.6247	5.2752	5.0764	4.1571	5.586
1810	7.5232	6.5081	8.3269	6.4535	7.7604	7.2286	7.5634	5.9267	6.9466	8.2151	7.5496	7.0731	7.7481	6.8135	6.5532	7.4084	9.1318	6.5213	8.4164	6.159
1820	9.2513	8.9724	7.9744	8.7772	8.1789	9.1674	9.2151	9.194	9.8588	8.004	10.585	9.366	10.746	9.31	9.75	9.9795	8.4992	10.888	10.831	8.671
1830	11.583	11.314	12.32	12.681	13.597	13.041	12.237	11.541	9.5919	15.407	14.023	11.742	15.005	15.24	14.96	11.777	13.613	11.625	12.148	13.16
1840	11.845	16.637	16.956	16.772	16.943	16.672	18.462	18.208	17.897	15.245	16.447	15.745	14.48	18.664	17.292	16.249	15.259	20.209	17.481	16.50
1850	24.547	21.021	18.498	21.1	21.344	22.661	21.55	22.366	27.382	23.624	24.091	20.899	20.012	22.968	22.387	22.854	25.481	22.235	24.901	26.08
1860	30.5	30.503	34.042	31.967	29.222	28.157	35.126	36.955	34.663	34.851	30.461	32.511	26.772	35.511	32.834	29.24	32.428	26.842	32.608	35.61
1870	37.838	36.815	36.999	43.489	43.546	37.352	41.652	44.431	42.116	39.168	35.127	44.765	38.439	34.567	37.538	39.881	41.117	36.212	41.288	36.35
1880	52.236	48.143	59.799	48.939	46.135	54.048	51.644	51.023	48.997	61.724	53.386	52.848	47.11	48.452	52.425	62.073	48.8	54.891	49.634	54.59
1890	53.972	59.733	60.441	61.613	55.12	73.874	62.92	61.121	64.038	80.214	63.324	68.273	71.166	71.785	62.052	59.867	64.442	69.542	62.656	71.67
1900	70.456	85.373	79.11	59.268	77.632	67.18	78.779	84.756	77.856	77.051	74.578	86.198	64.941	87.418	75.861	80.921	87.191	77.218	76.669	78.43
1910	102.56	97.615	81.49	84.874	110.5	113.87	124.45	81.452	92.887	74.455	94.684	69.004	75.97	98.719	96.239	82.483	71.069	94.644	84.735	106.9
1920	112.02	106.32	99.095	90.973	105.97	121.83	104.51	112.82	96.922	101.84	116.14	103.93	107.87	110.89	120.1	119.86	88.436	112.39	120.74	116.9
1930	107.07	104.79	108.45	118.06	126.59	124.87	103.69	114.58	118.47	112.39	127.63	127.14	137.45	115.6	128.35	110.9	127.9	104.88	122.88	125.4
1940	102.68	110.29	136.87	138.62	119.34	127.73	156.92	126.43	129.4	121.63	134.26	141.15	121.13	141.51	153.41	134.45	123.08	124.04	140.74	143.2
1950	142.09	121.09	170.32	173.66	175.93	140.17	159.89	140.58	143.46	133.71	154.92	131.04	131.63	138.22	120.13	141.38	146.23	123.12	137.82	153.6
1960	182.83	225.63	168.37	211.19	181.24	193.91	167.4	189.3	193.98	180.4	179.92	160.99	176.33	189.28	170.96	188.17	152.21	170.96	159.75	171.5
1970	224.32	224.93	213.95	202.6	215.87	190.76	258.66	189.05	257.04	248.19	189.12	221.21	171.45	210.78	209.84	205.23	186.45	224.46	203.14	212.3
1980	228.62	232.32	215.08	219.25	204.94	216.04	238.98	202.41	196.53	210.29	244.32	223.86	226.89	252.31	207.58	225.5	217.35	242.75	220.77	227.3
1990	220.79	224.47	251.24	269.03	269.94	270.68	256.02	262.45	251.89	241.72	283.74	262.46	269.3	238.11	216.97	322.04	230.65	305.6	278.42	239.6

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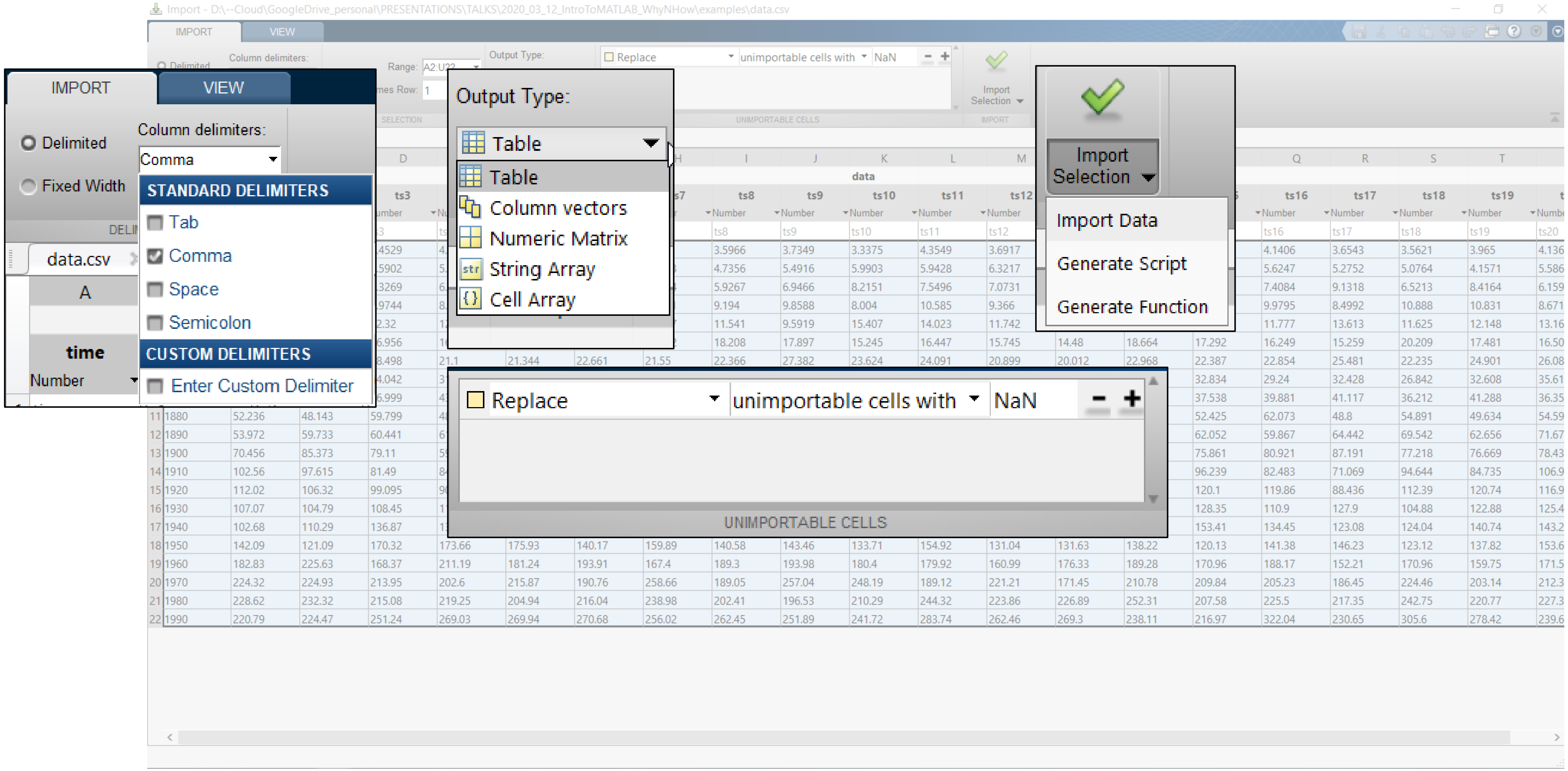
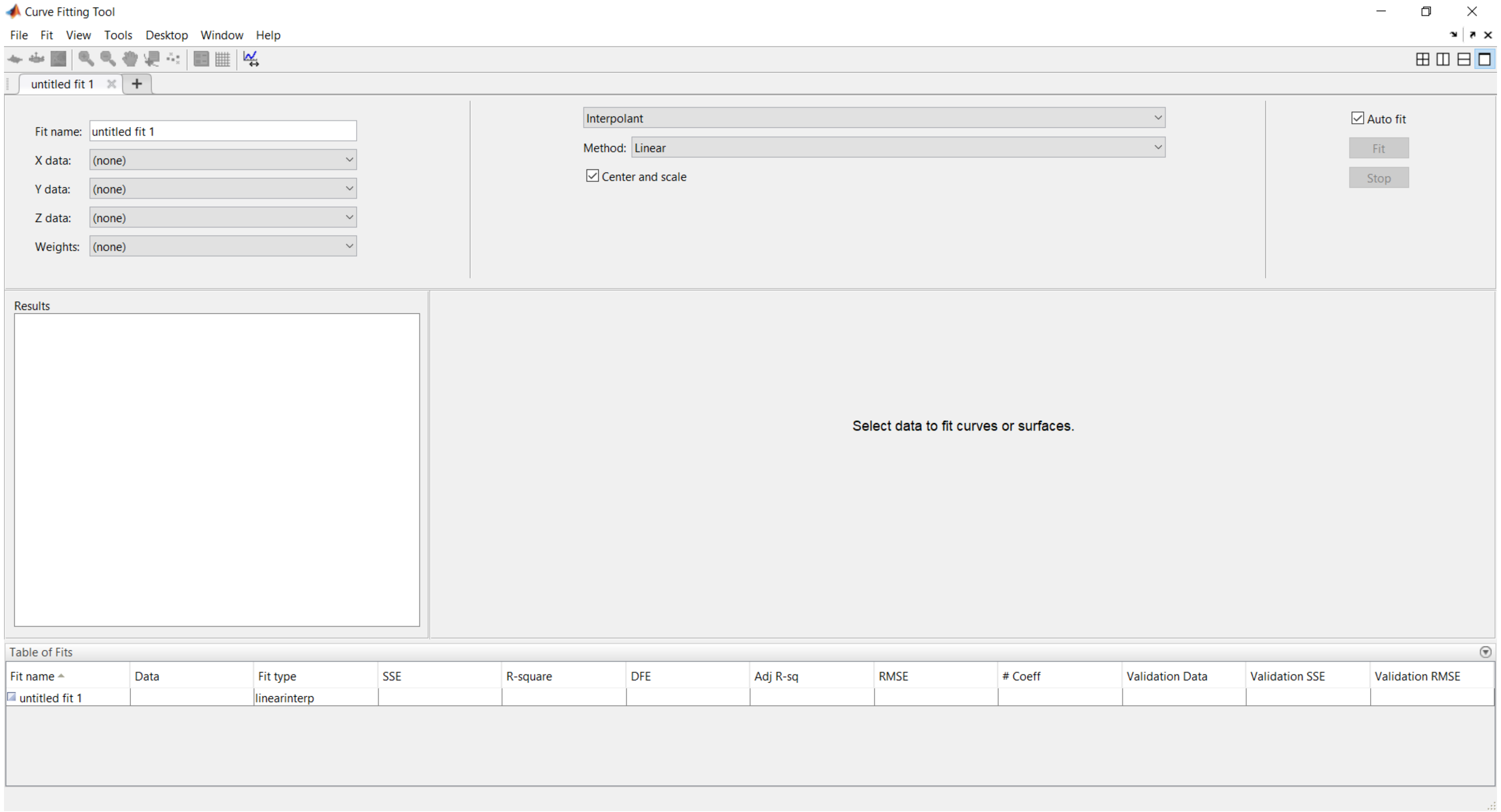
Matlab APPS

INTERACTIVE DATA IMPORT



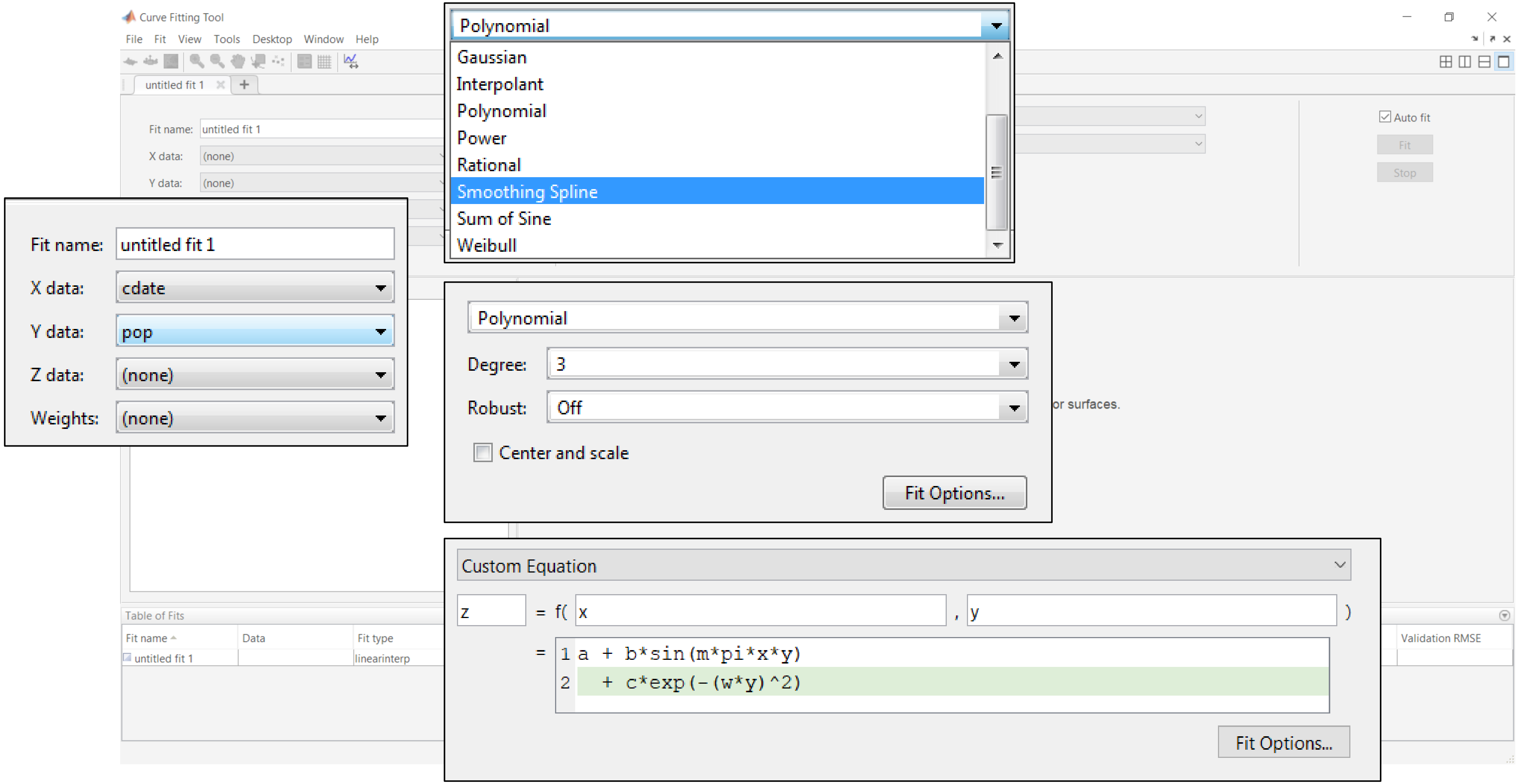
Matlab APPS

CURVE FITTING



Matlab APPS

CURVE FITTING



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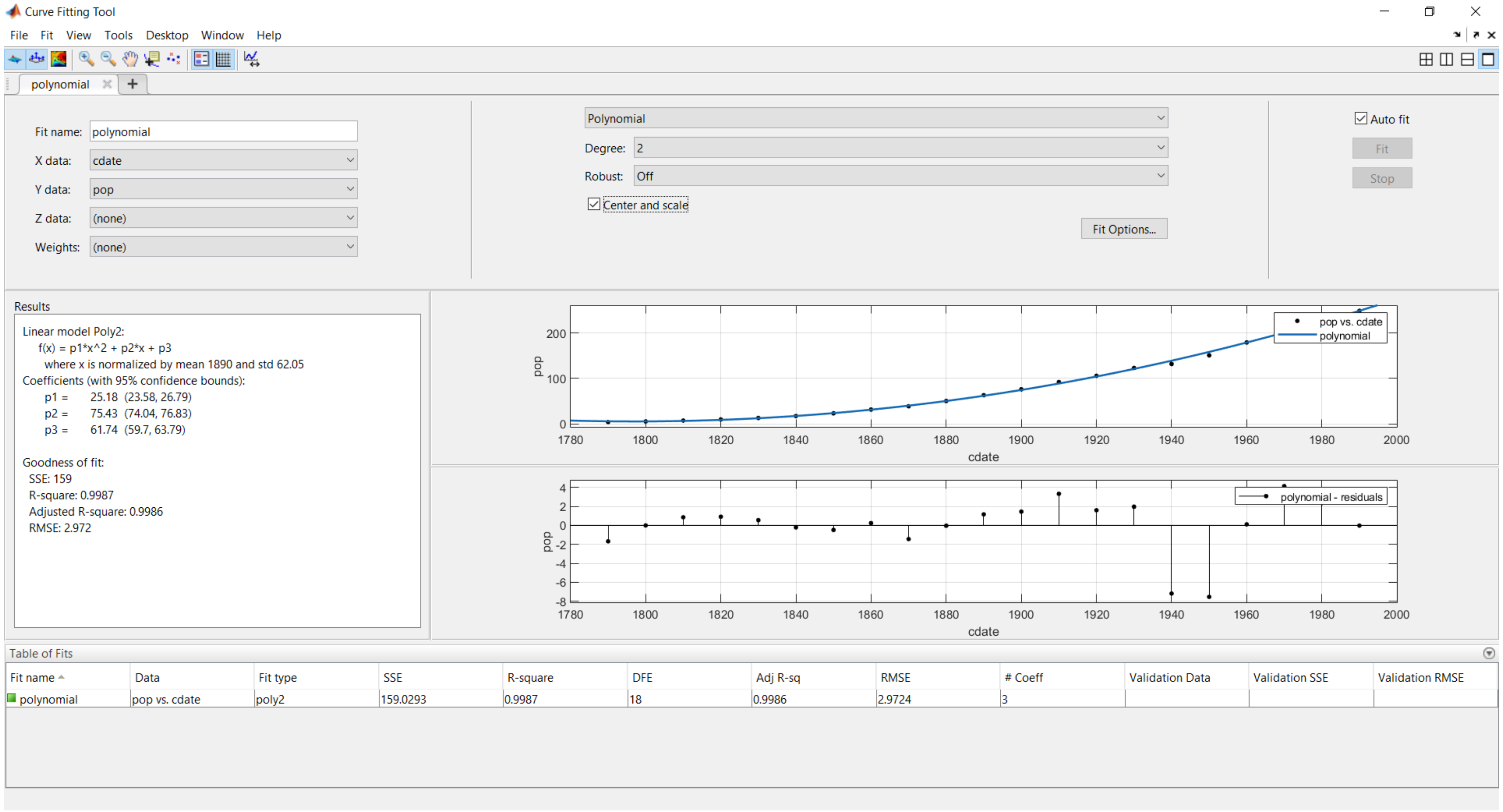
Matlab APPS

CURVE FITTING



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Matlab APPS

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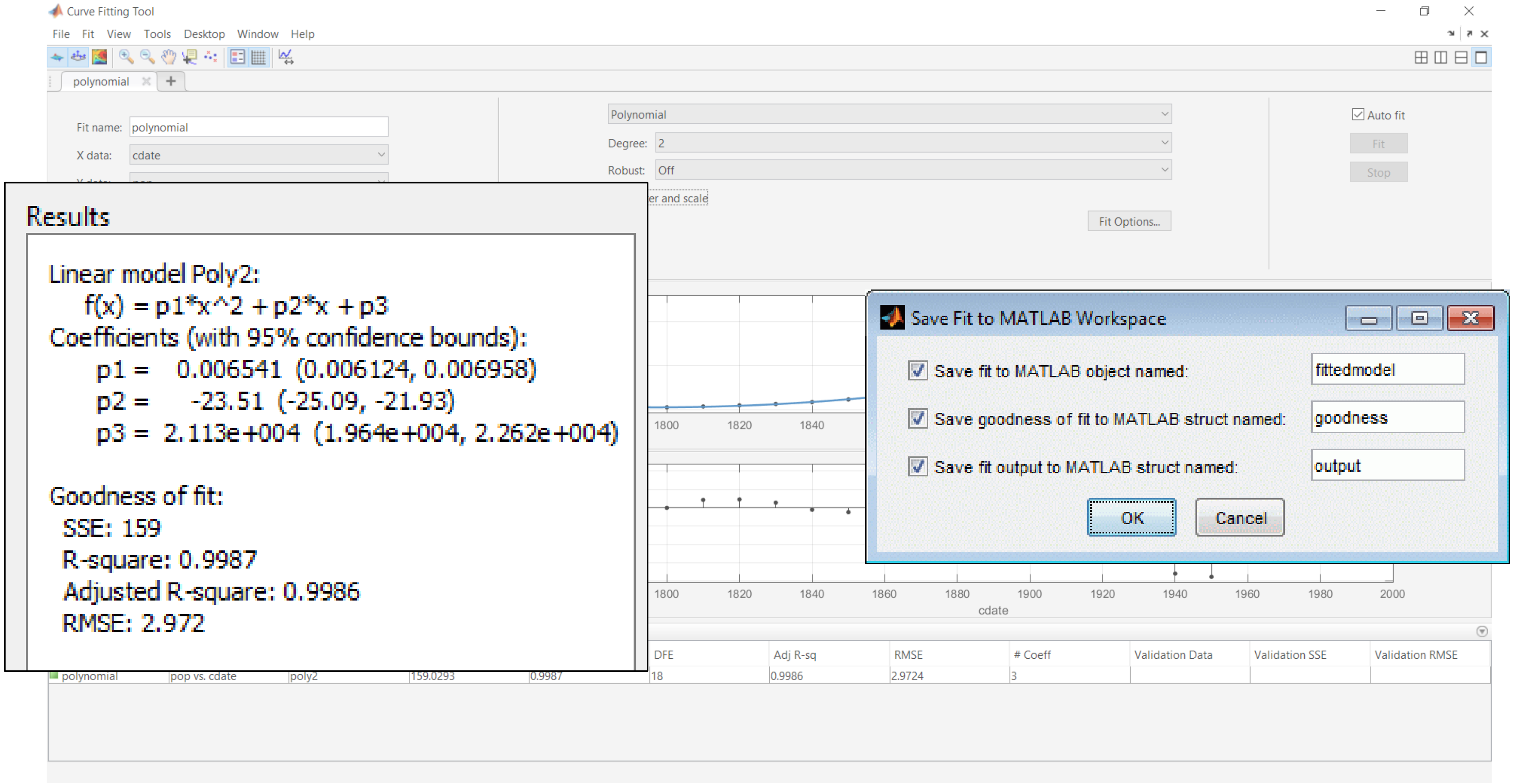

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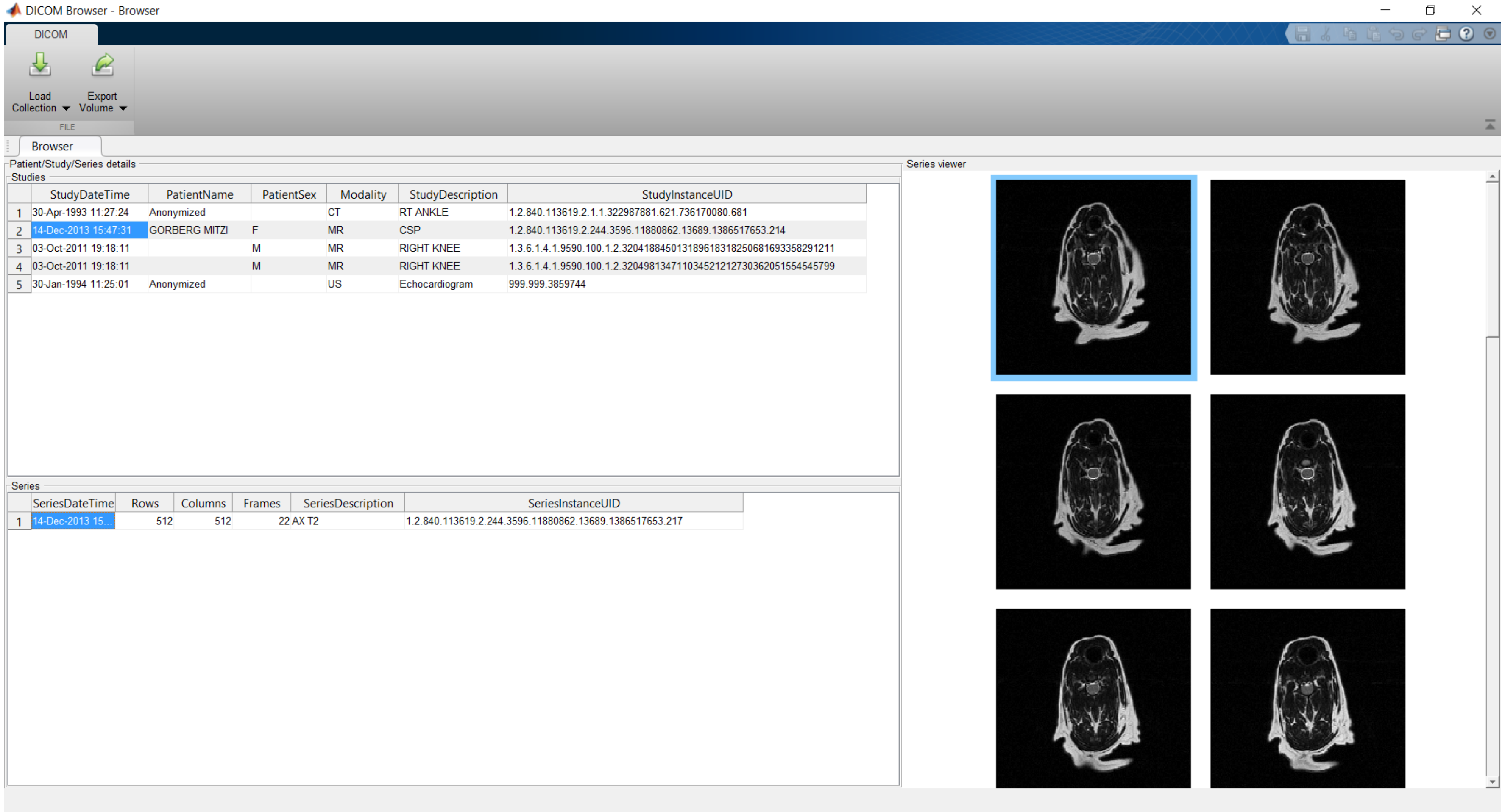
Matlab APPS

DICOM BROWSER



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Matlab APPS

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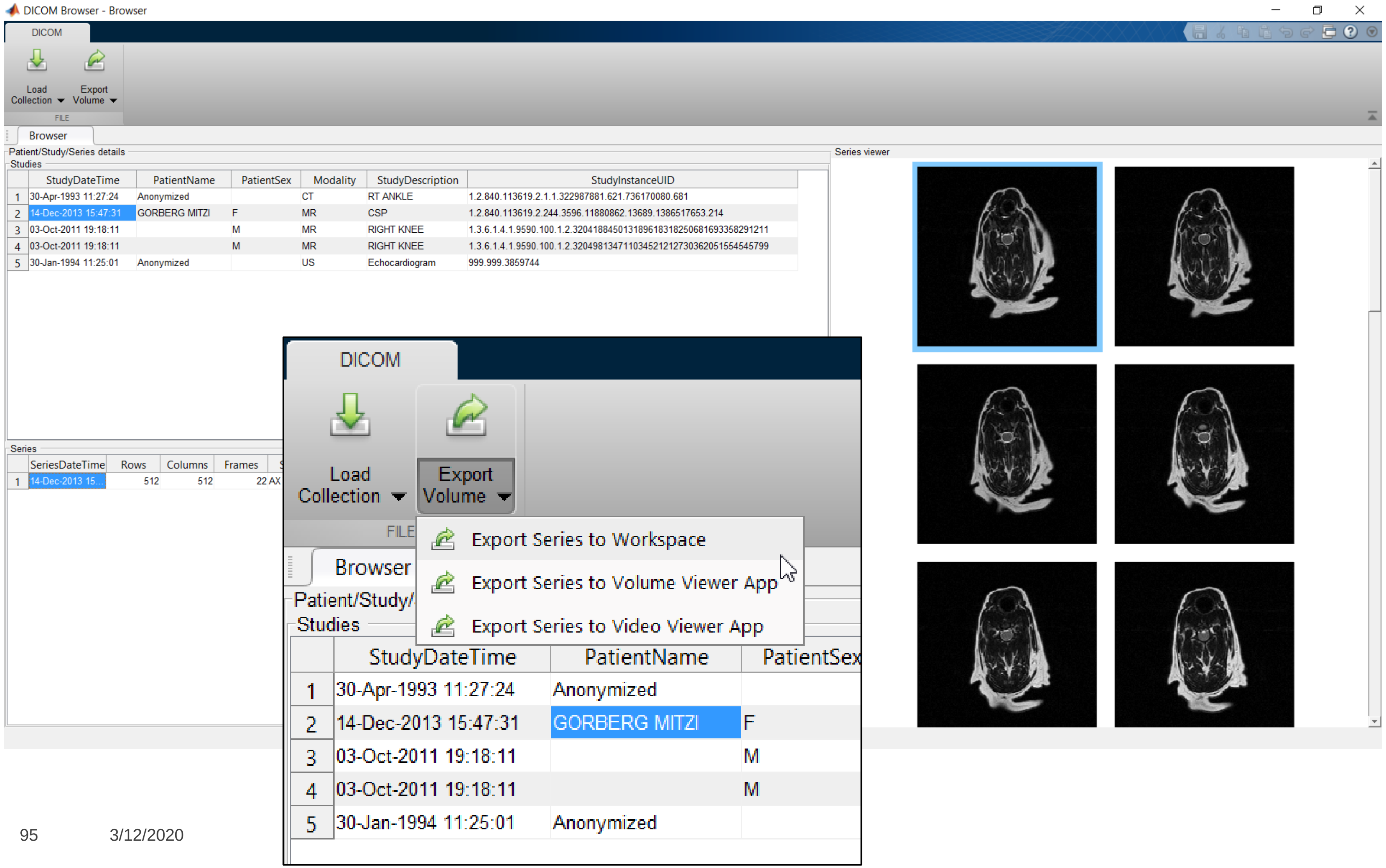
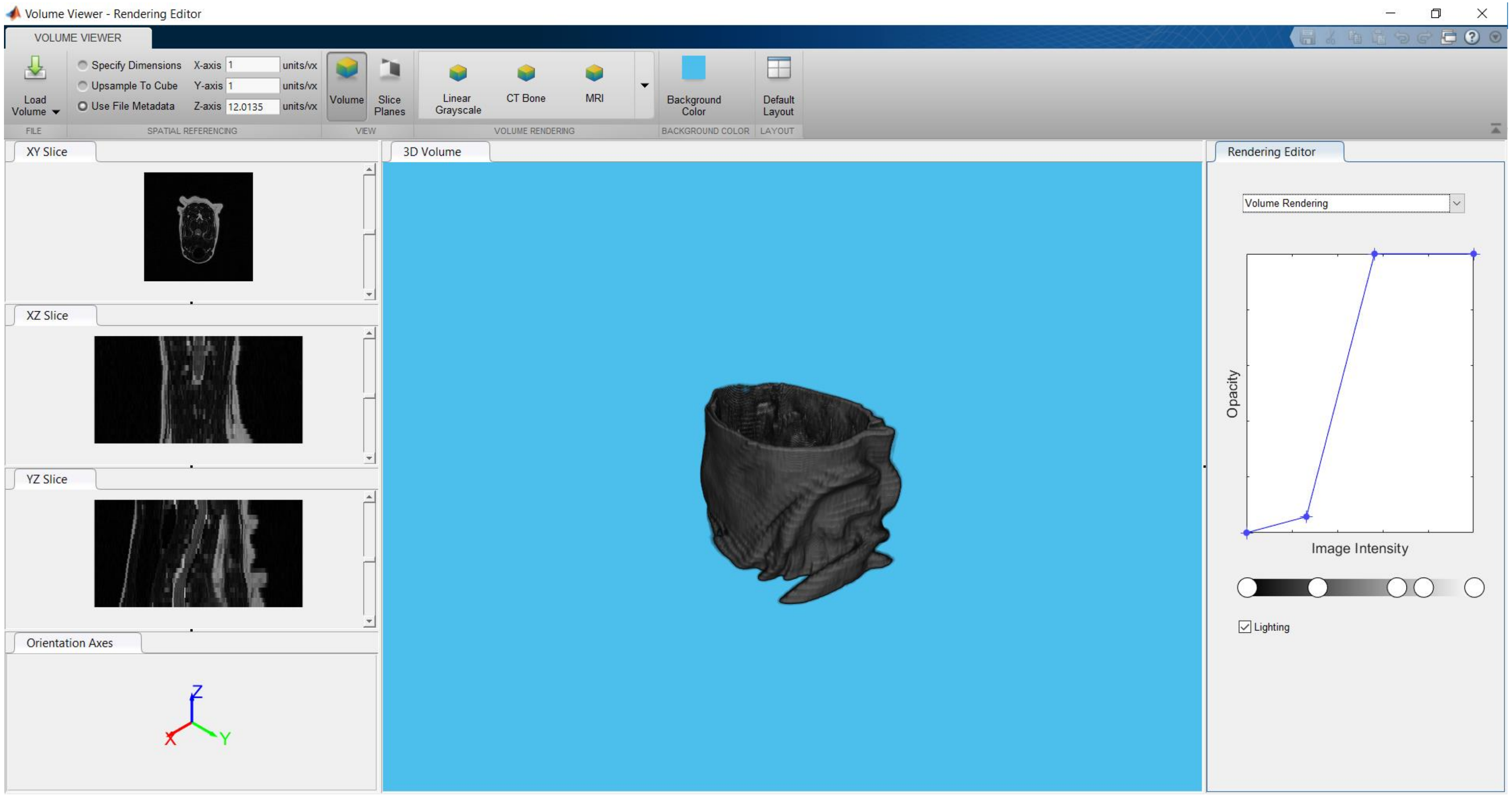


Matlab APPS

VOLUME VIEWER



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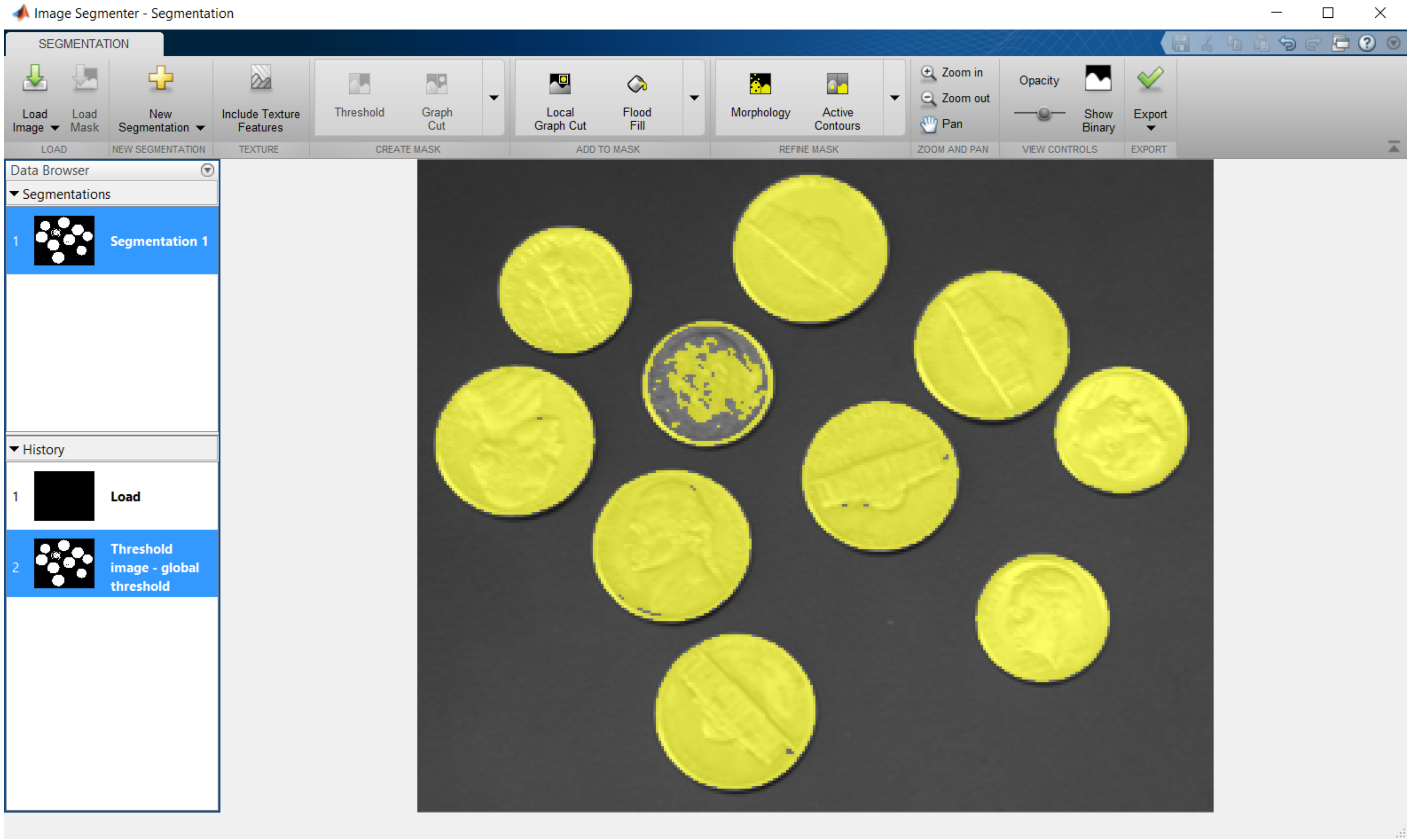
Matlab APPS

IMAGE SEGMENTER



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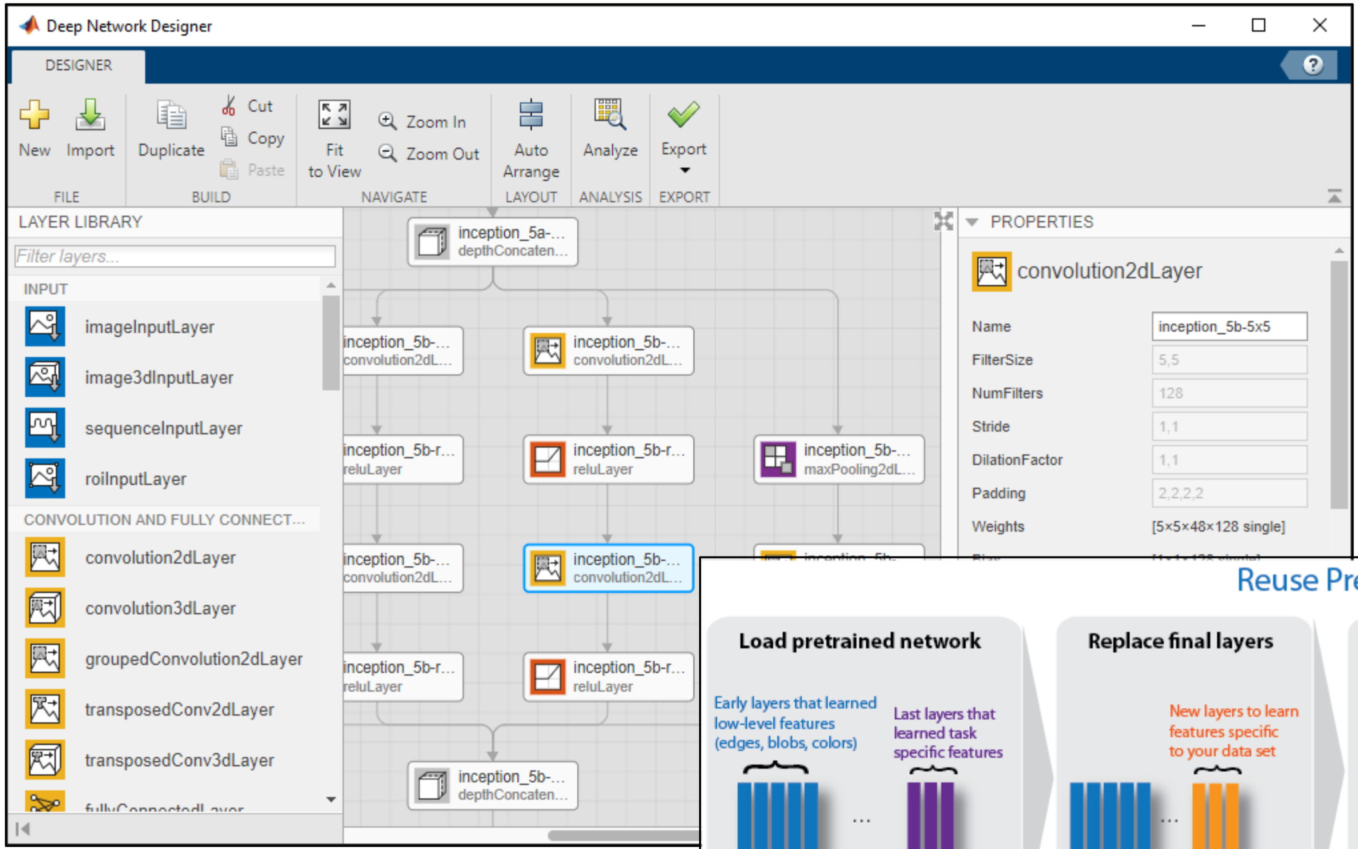
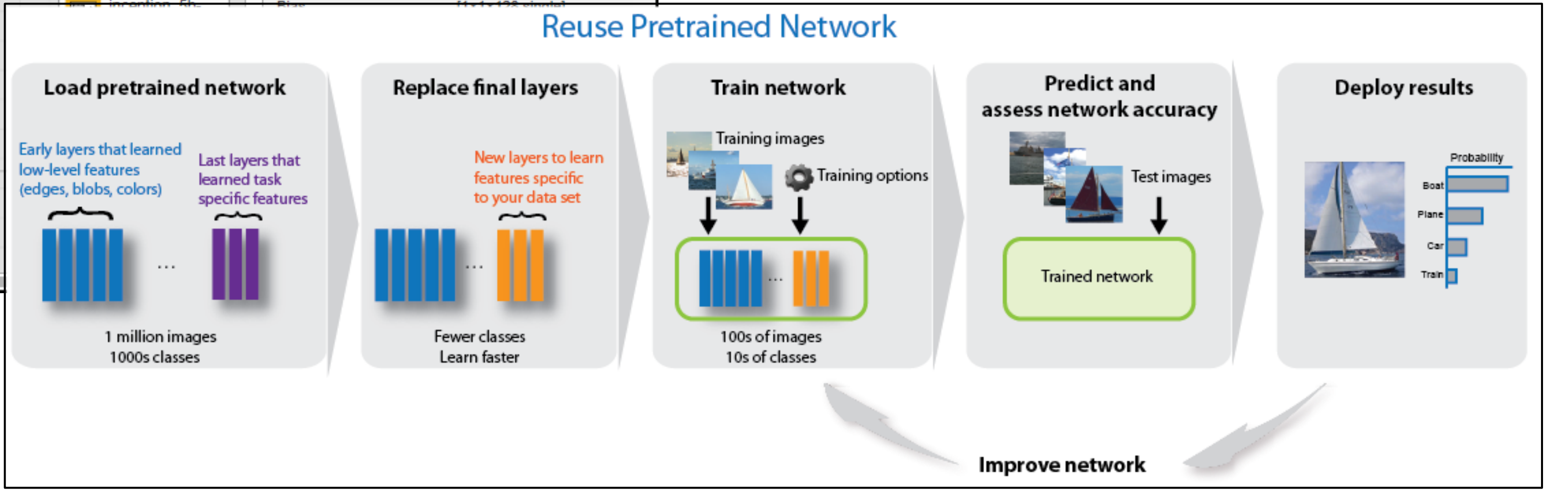
Matlab APPS

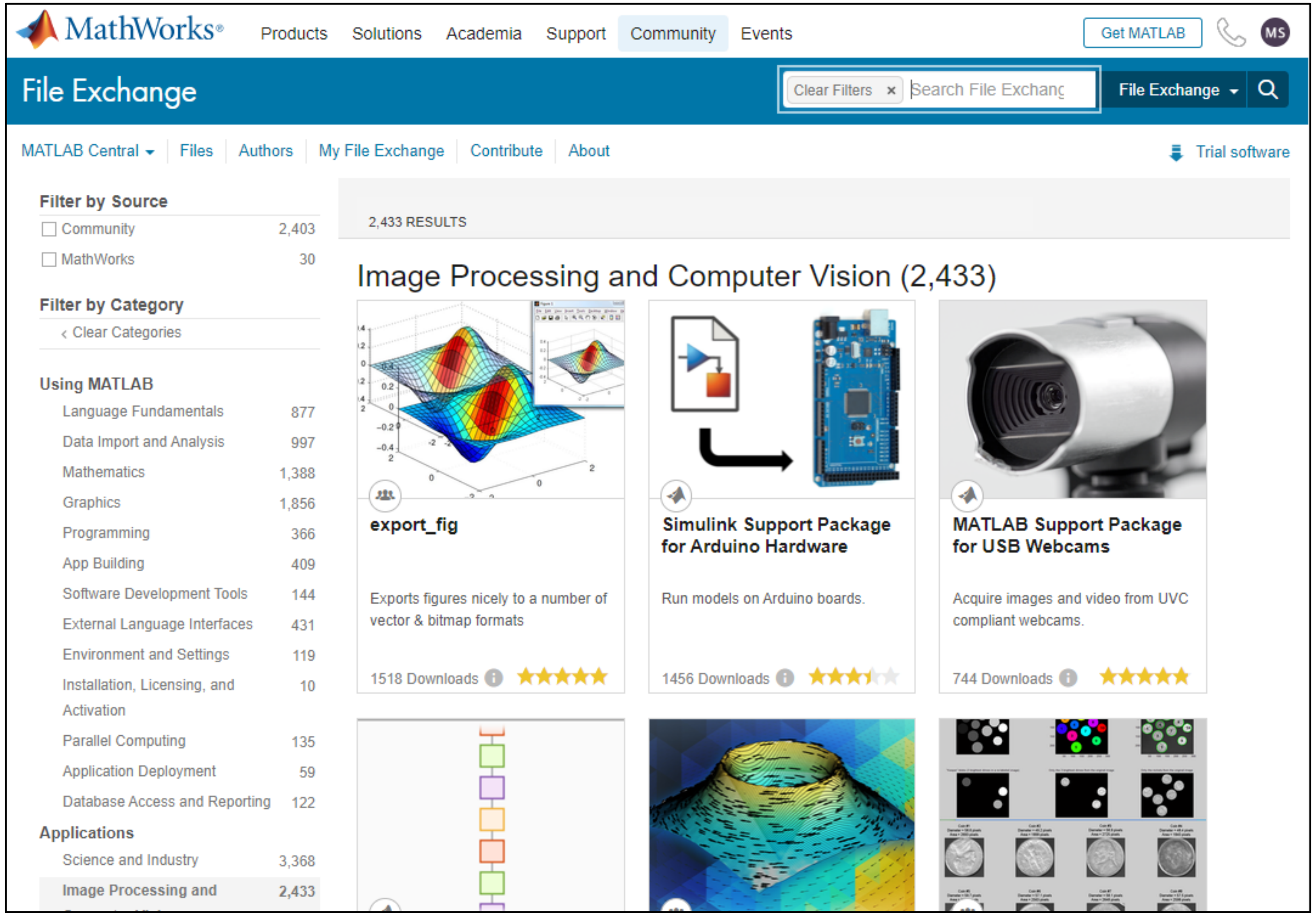
DEEP LEARNING NETWORK DESIGNER

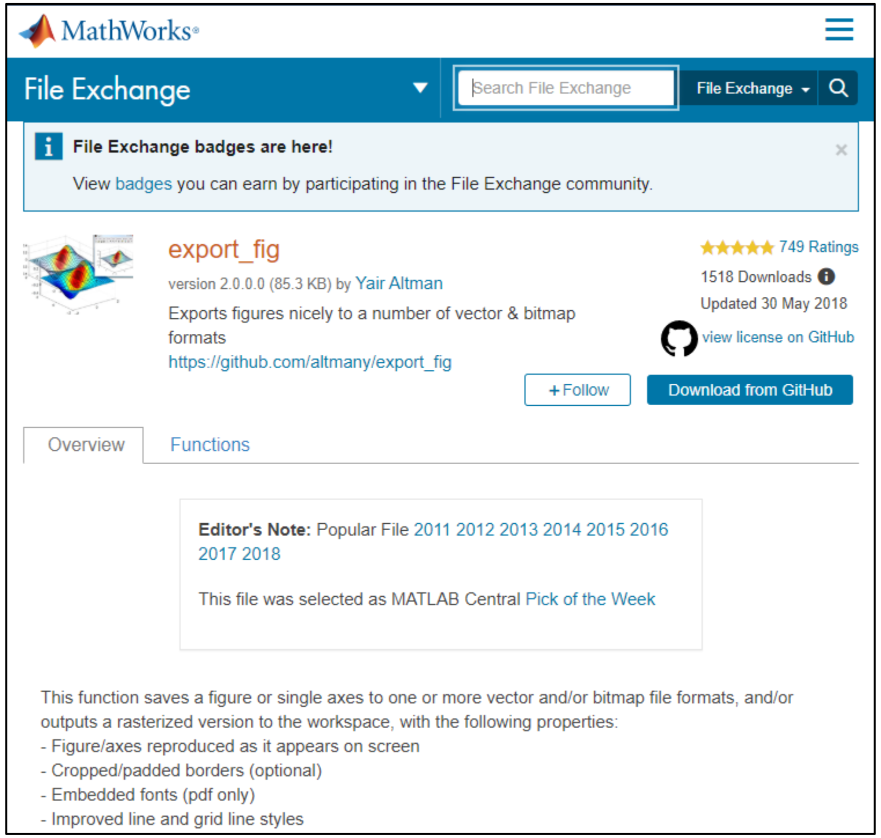




Mathworks File Exchange Platform

SHARING CODE, CUSTOM TOOLBOXES AND APPS WITH OTHER USERS





(Neuro)Science community options

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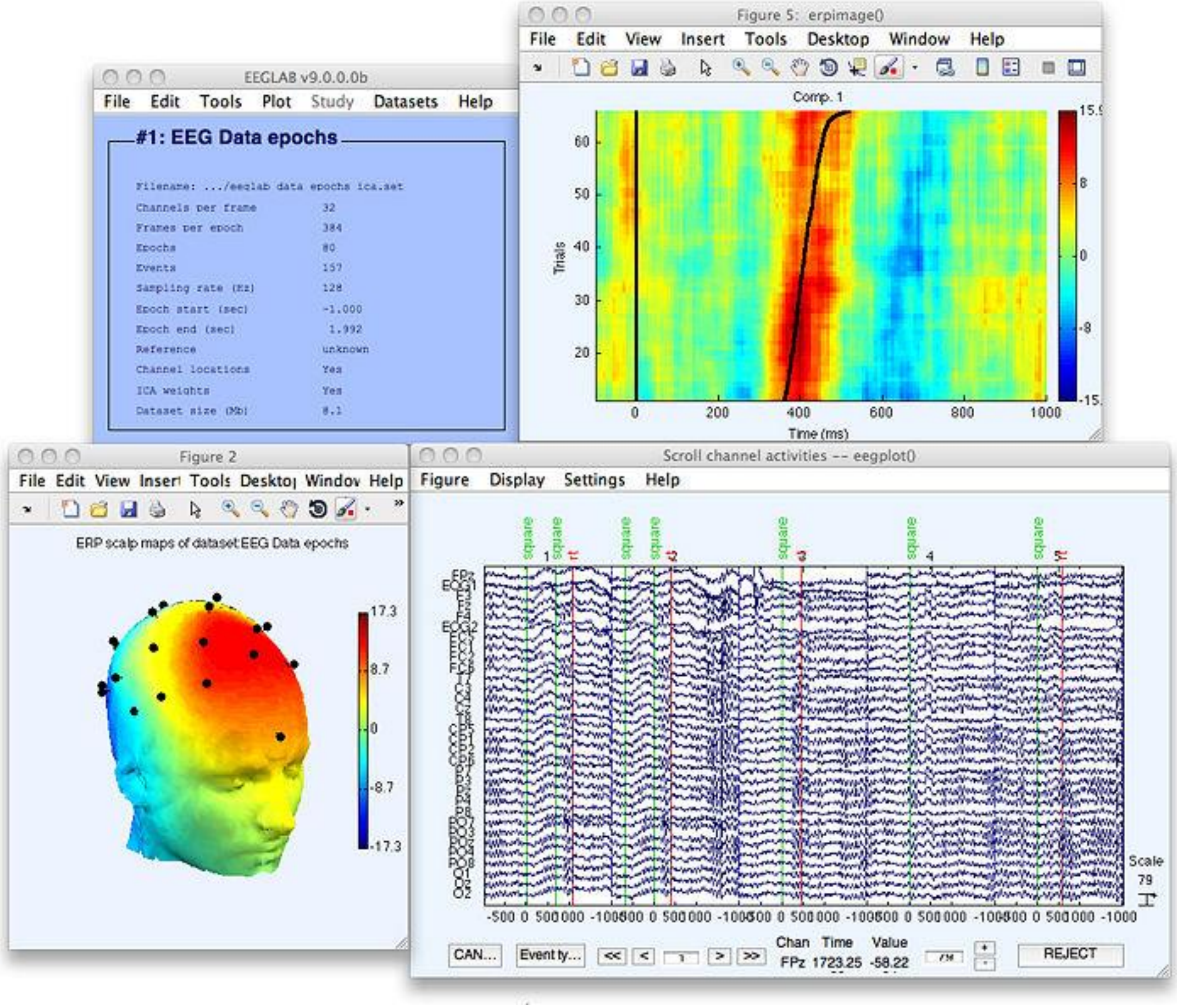
EEGLAB

https://sccn.ucsd.edu/eeglab/index.php

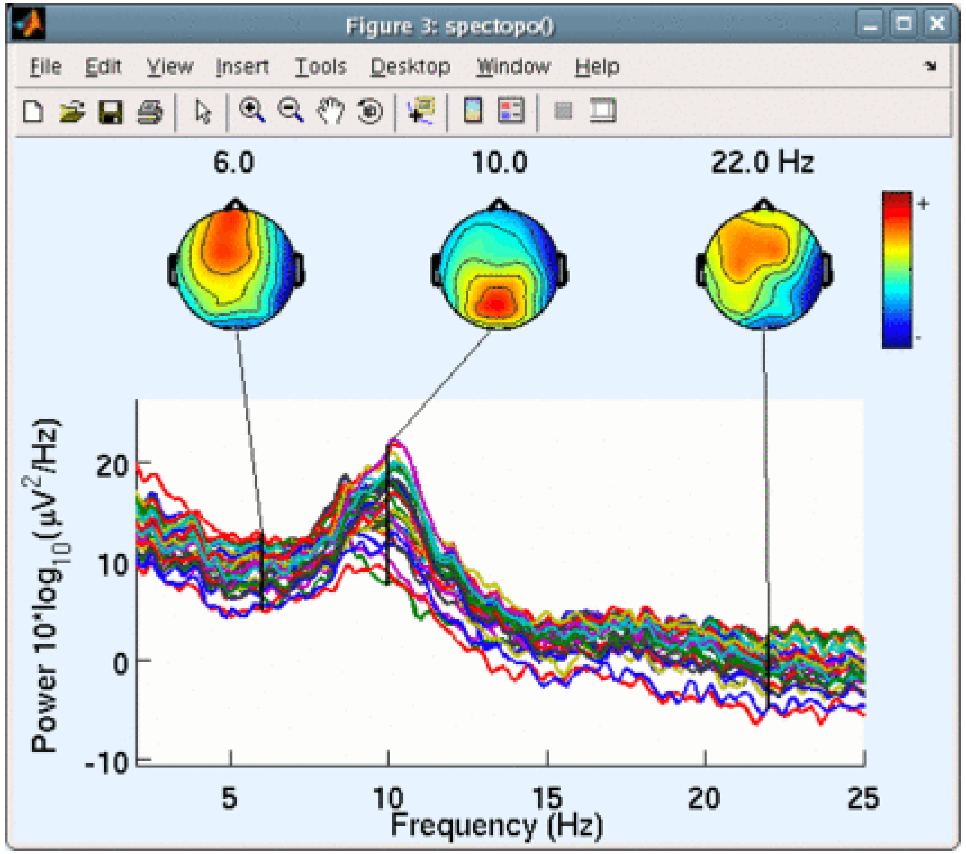


EEGLAB is an interactive Matlab toolbox for processing continuous and event-related ***EEG, MEG and other electrophysiological data:***

- It provides a **GUI** to interactively process high-density EEG
- It allows building and running **batch or custom data analysis scripts**
- It offers a structured environment for ***storing, accessing, measuring, manipulating and visualizing*** event-related EEG data
- It's an **open-source platform** through which researchers can share new methods as **EEGLAB plug-in functions**

EEGLAB

https://sccn.ucsd.edu/eeglab/index.php



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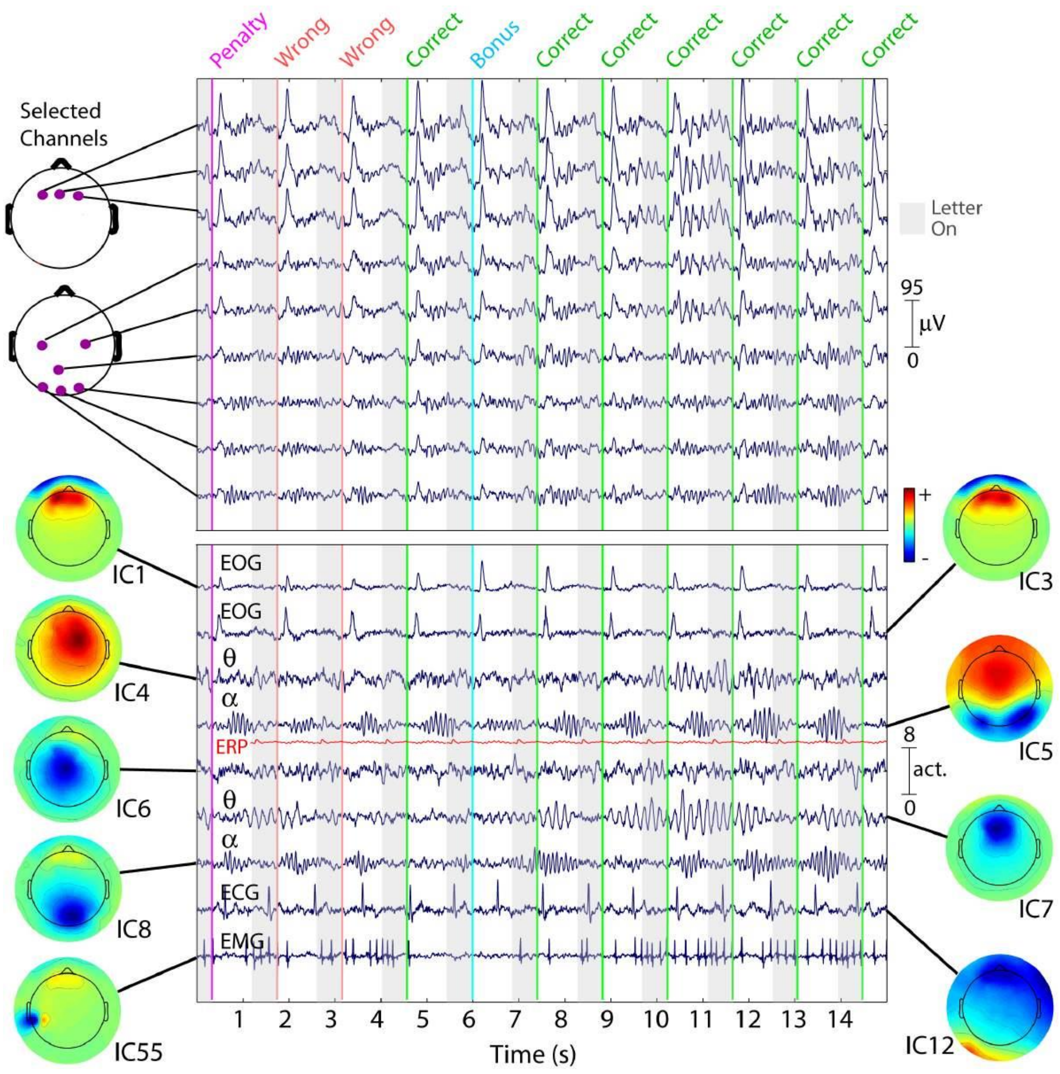
EEGLAB

https://sccn.ucsd.edu/eeglab/index.php



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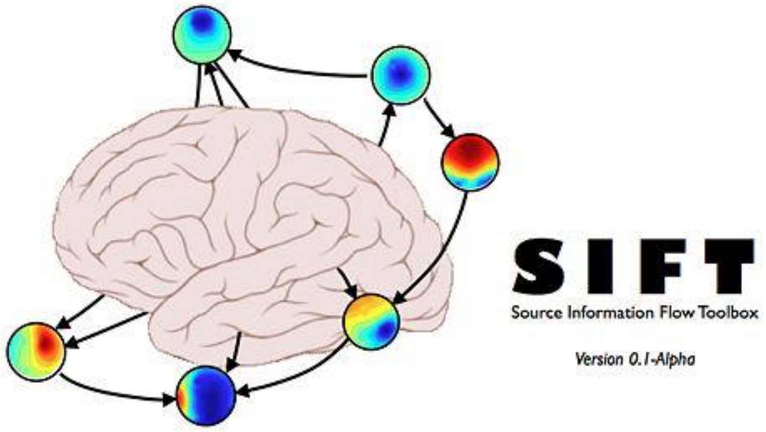
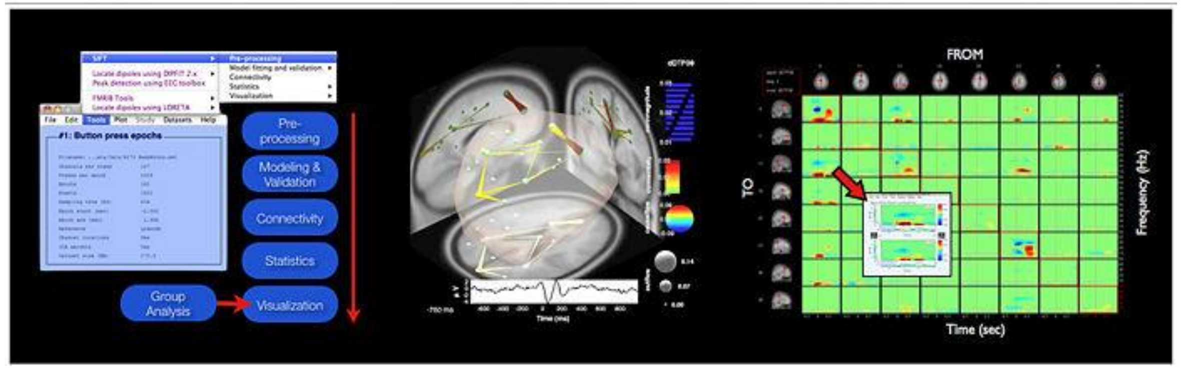
EEGLAB - SIFT

https://sccn.ucsd.edu/wiki/SIFT

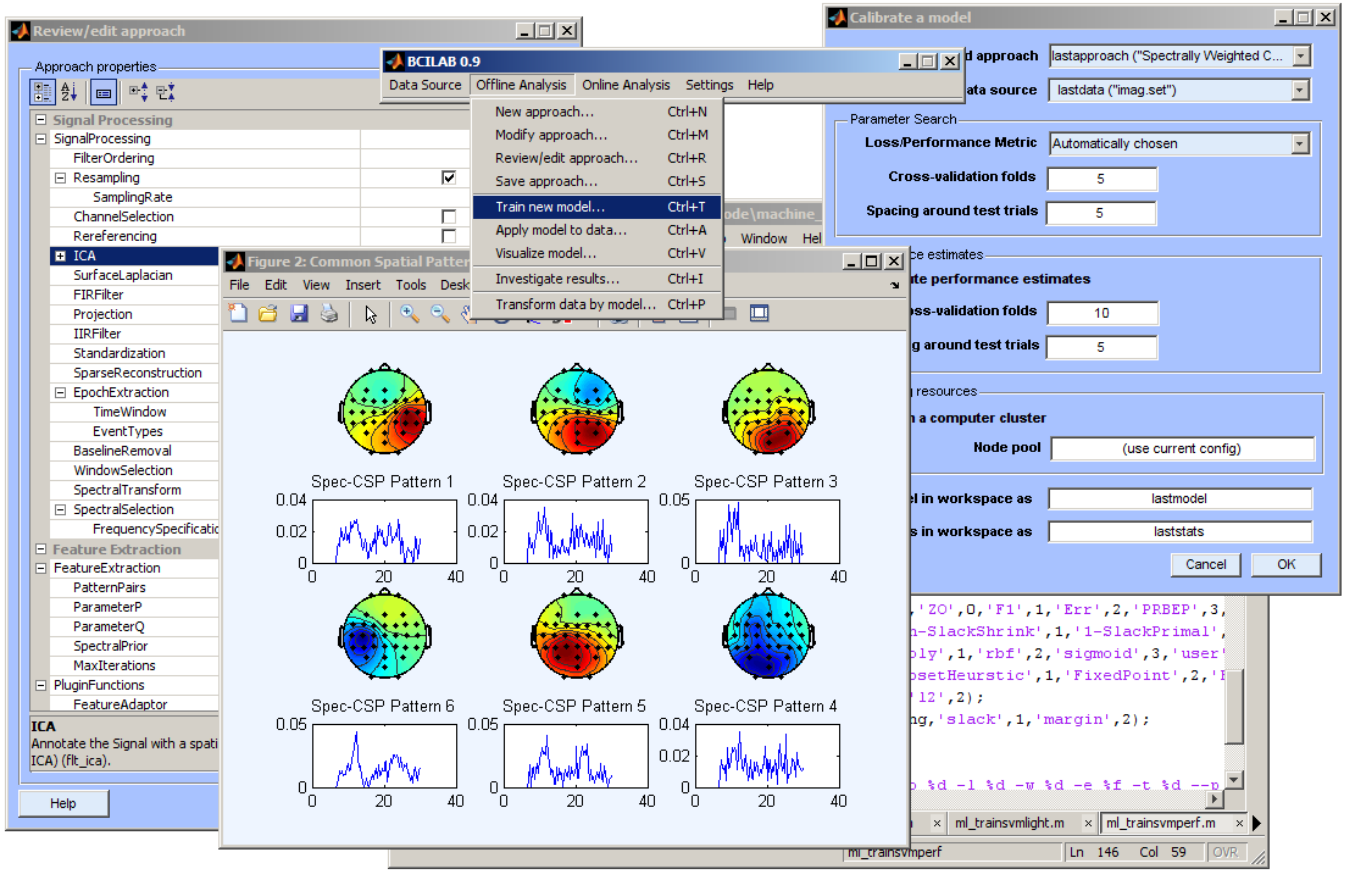




EEGLAB-compatible toolbox for **analysis and visualization of multivariate causality and information flow** between sources of electrophysiological (EEG/ECoG/MEG) activity.

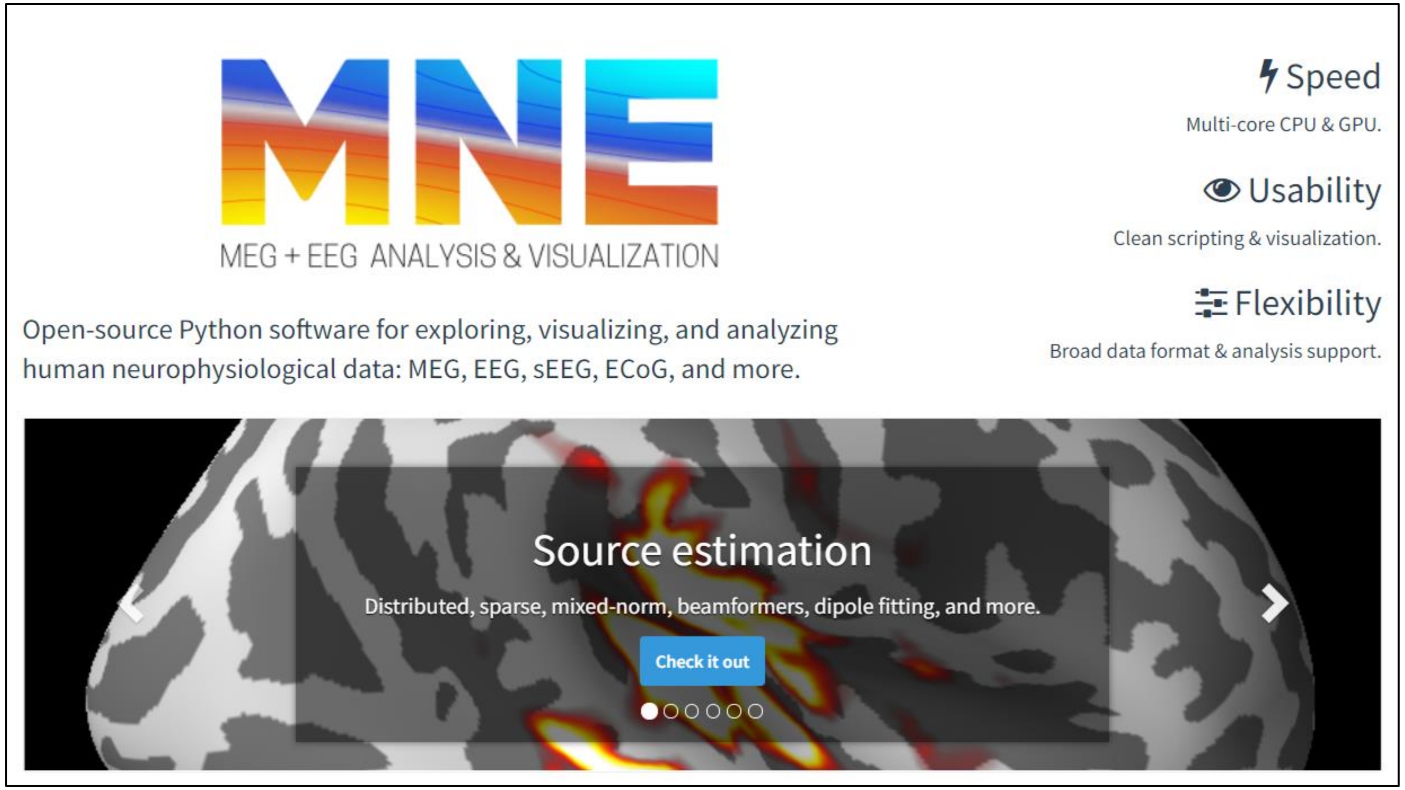
EEGLAB - BCILAB

https://sccn.ucsd.edu/wiki/BCILAB



MATLAB toolbox and EEGLAB plugin for the **design, prototyping, testing, experimentation with, and evaluation of Brain-Computer Interfaces** (BCIs), and other systems in the same computational framework.

MNE



MEG/EEG source analysis

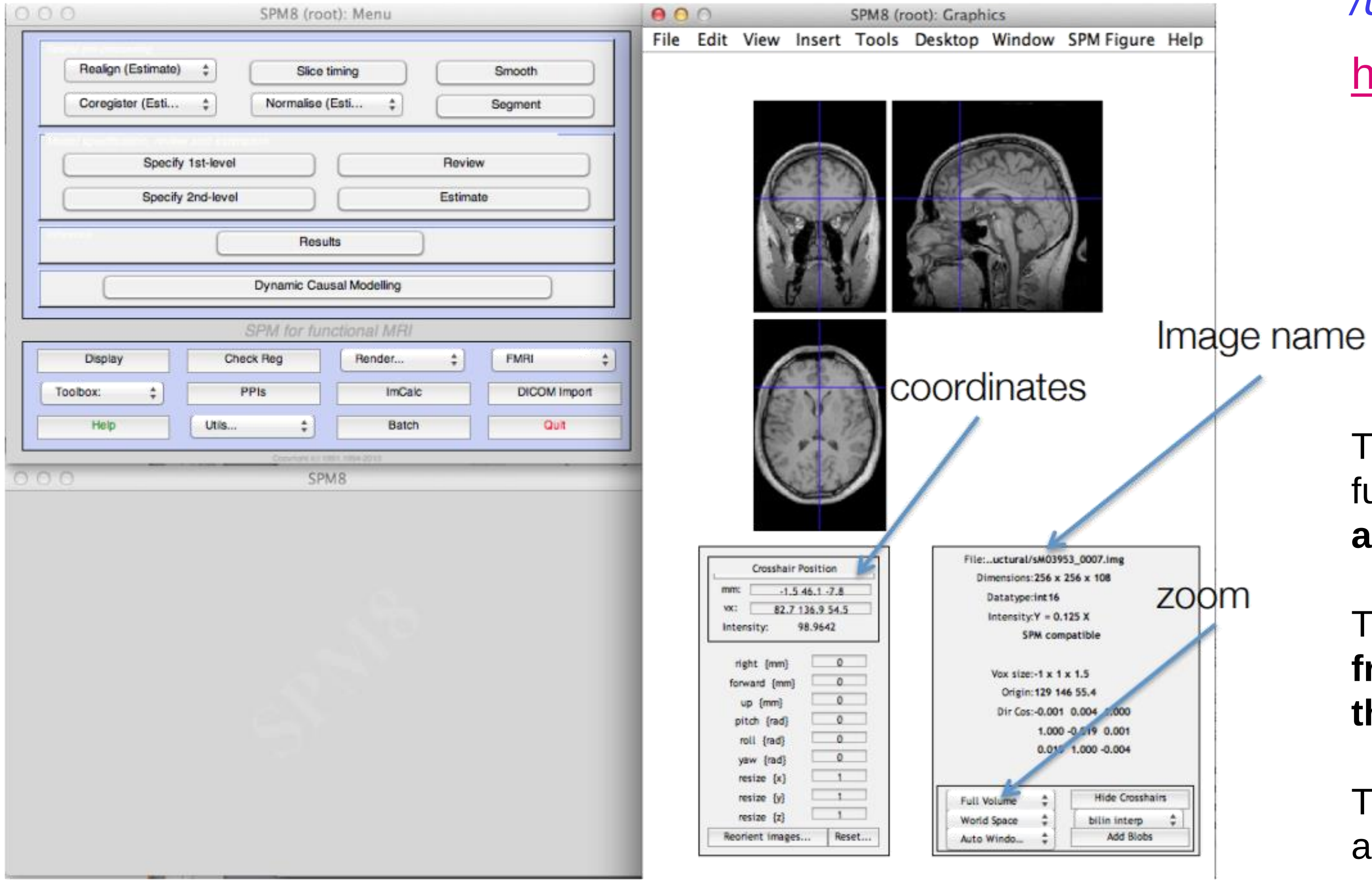
*/usr/pubsw/packages/**mne**/stable/share/matlab/*

https://mne.tools/stable/index.html

Statistical Parametric Mapping (SPM)

*/usr/pubsw/common/**spm***

https://www.fil.ion.ucl.ac.uk/spm/

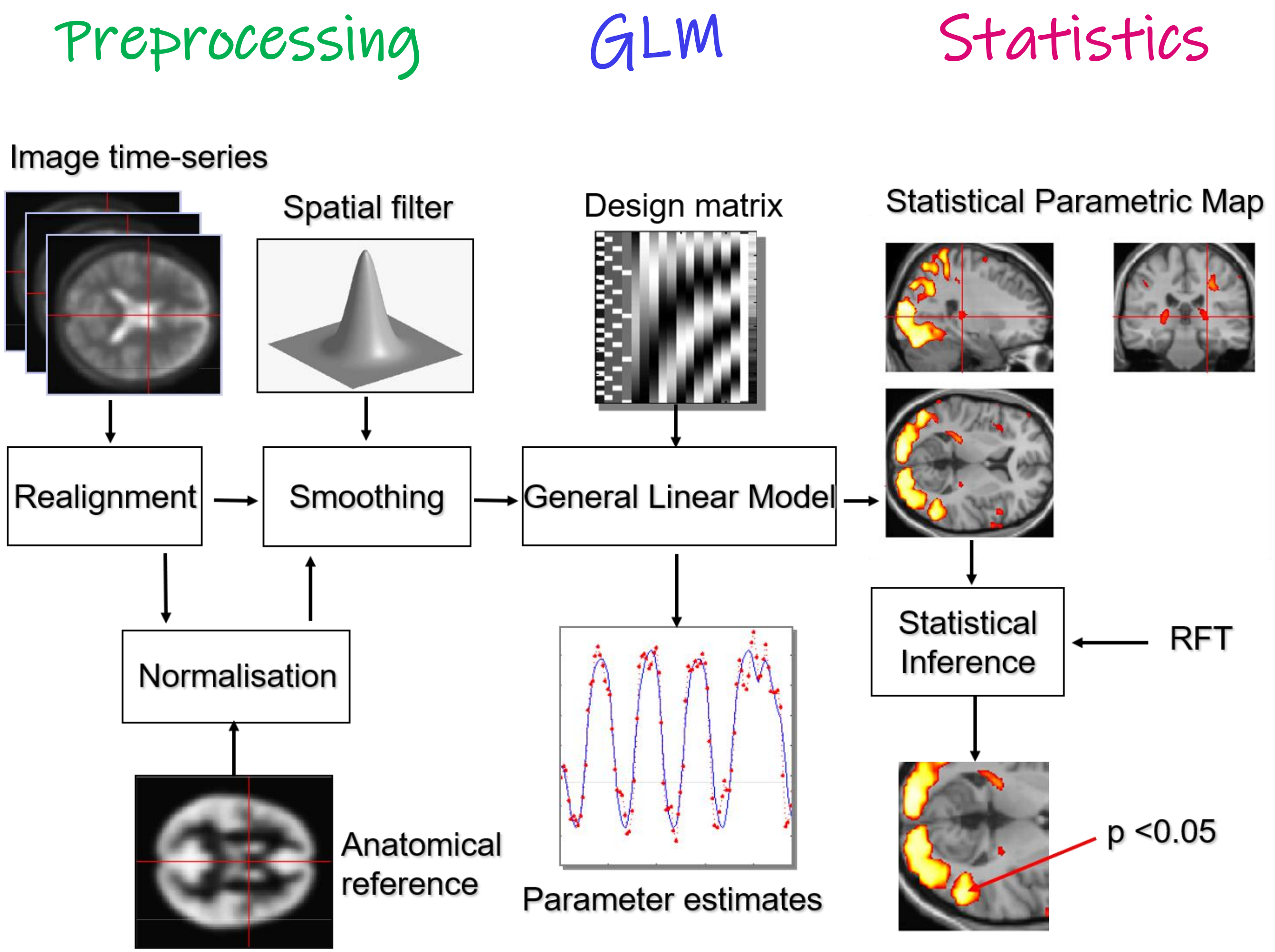


The SPM software is a suite of MATLAB functions and subroutines, designed for the **analysis of brain imaging data sequences.**

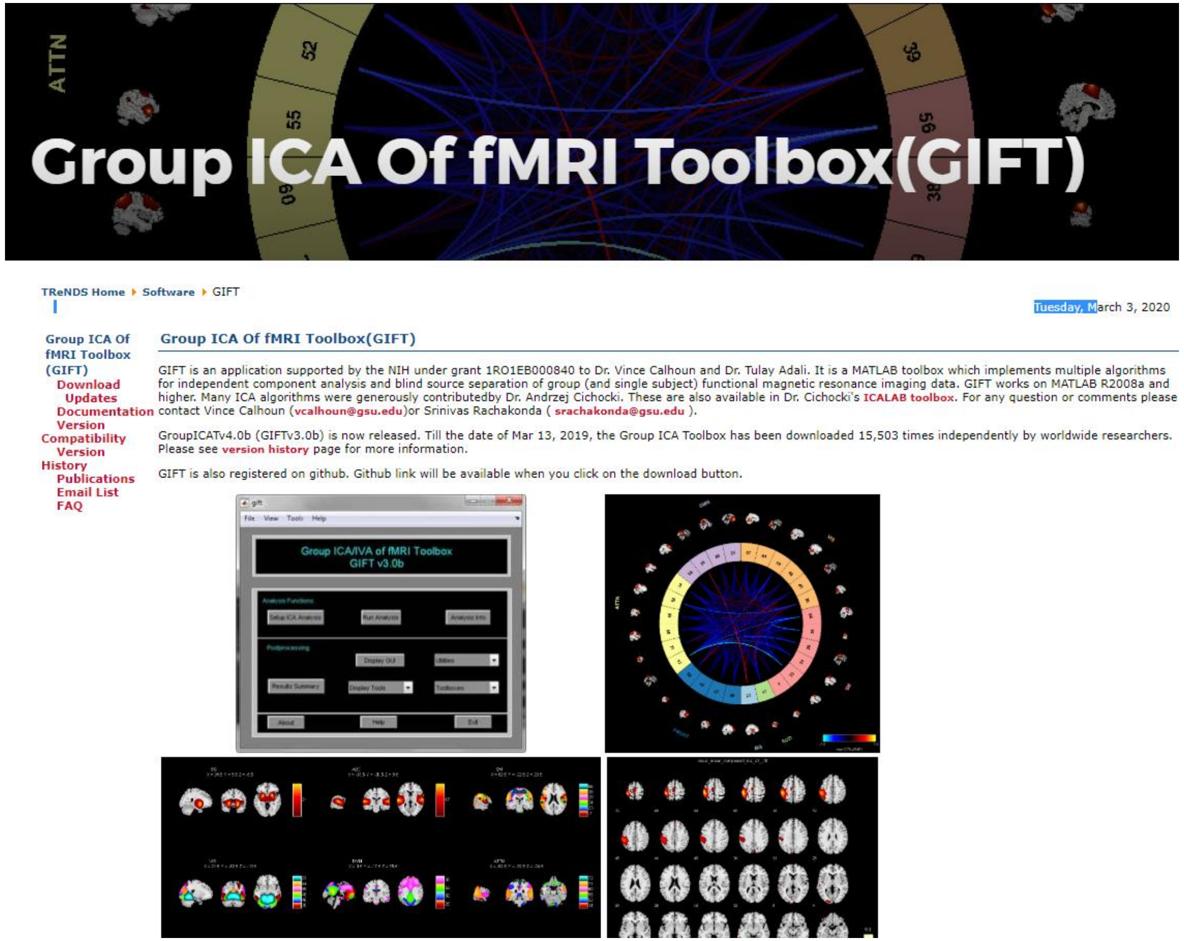
The sequences can be a **series of images from different cohorts, or time-series from the same subject.**

The current release is designed for the analysis of **fMRI, PET, SPECT, and MEG.**

Statistical Parametric Mapping (SPM)



GIFT (Group ICA of fMRI Toolbox)



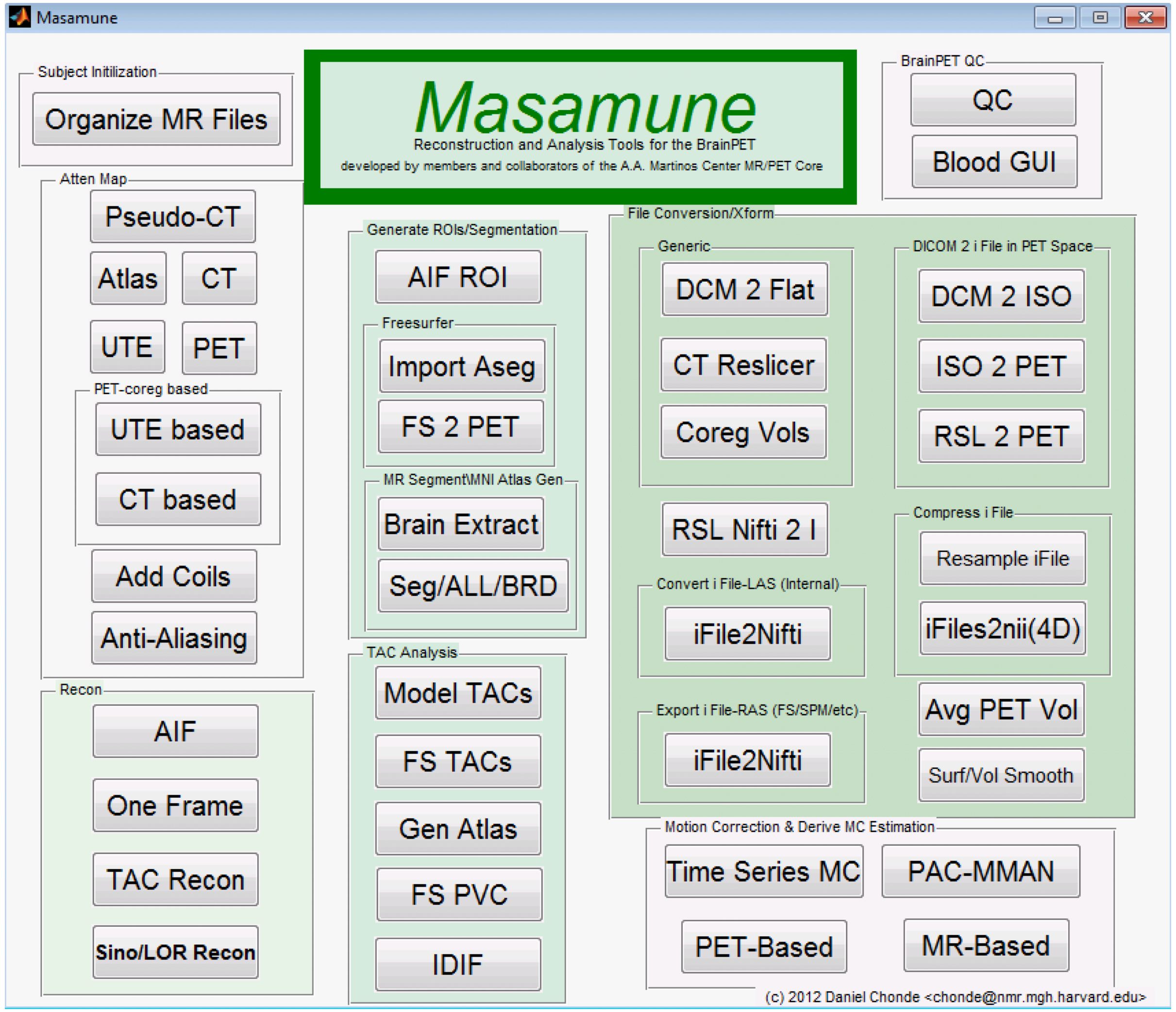
It is a MATLAB toolbox which implements multiple algorithms for **independent component analysis and blind source separation of group** (and single subject) **fMRI** data.

https://trendscenter.org/software/gift/

Athinoula A. Martinos Center For Biomedical Imaging

Masamune

http://people.fas.harvard.edu/~kastman/nwlabs_pipeline/pet-recon-mgh.html

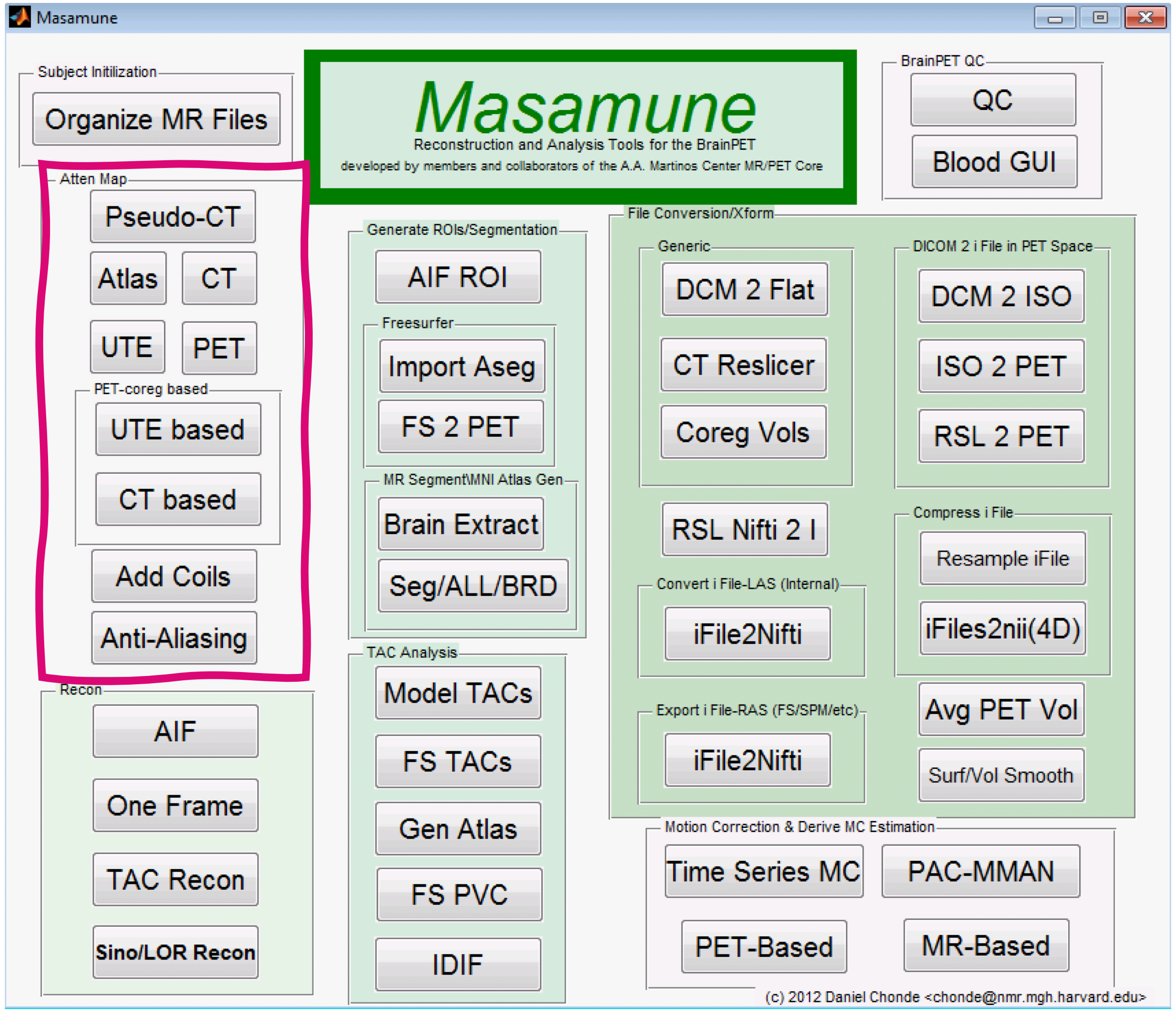


Matlab tool for reconstruction of 'BrainPET' PET-MR data (Bay 6)

Athinoula A. Martinos Center For Biomedical Imaging

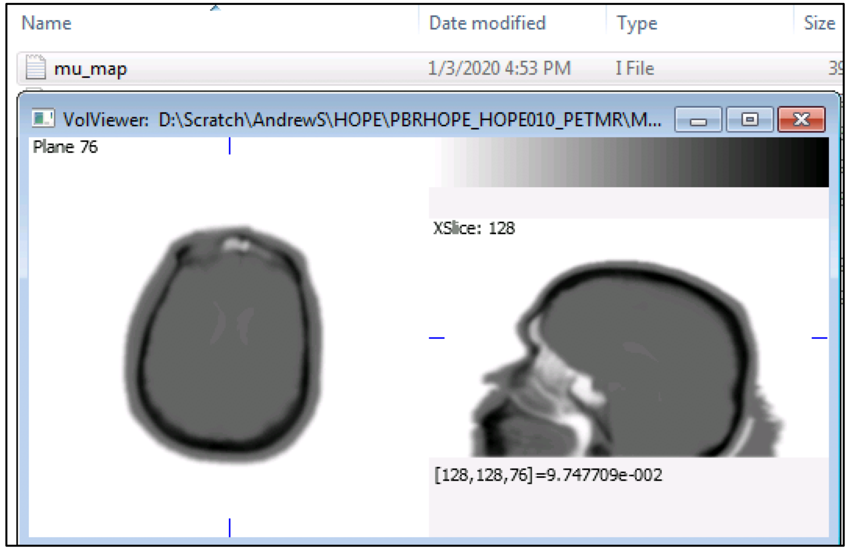
Masamune

http://people.fas.harvard.edu/~kastman/nwlabs_pipeline/pet-recon-mgh.html



Matlab tool for reconstruction of 'BrainPET' PET-MR data (Bay 6)

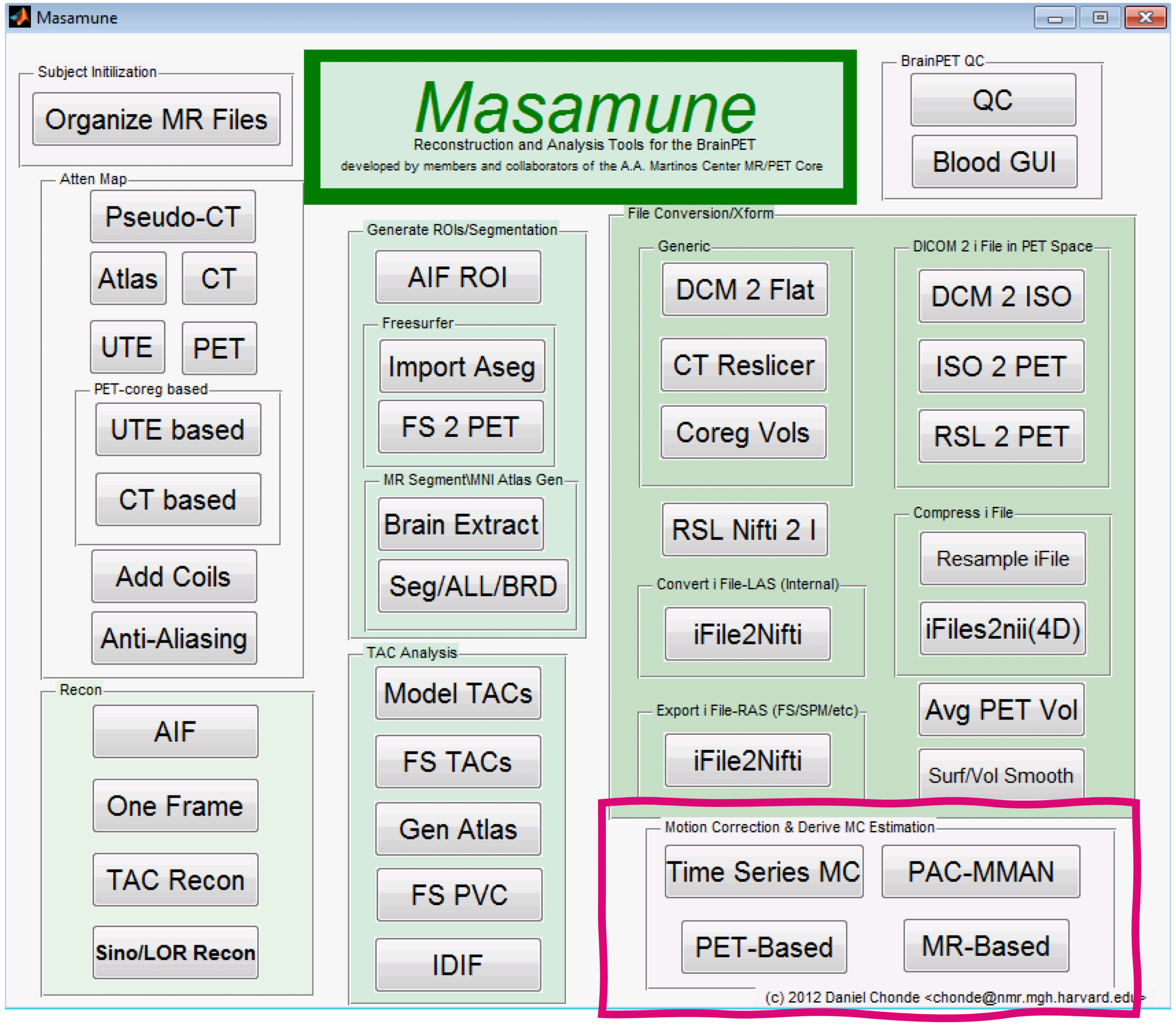
Attenuation correction



Athinoula A. Martinos Center For Biomedical Imaging

Masamune

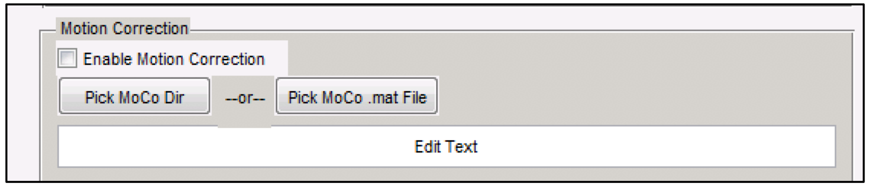
http://people.fas.harvard.edu/~kastman/nwlabs_pipeline/pet-recon-mgh.html



Matlab tool for reconstruction of 'BrainPET' PET-MR data (Bay 6)

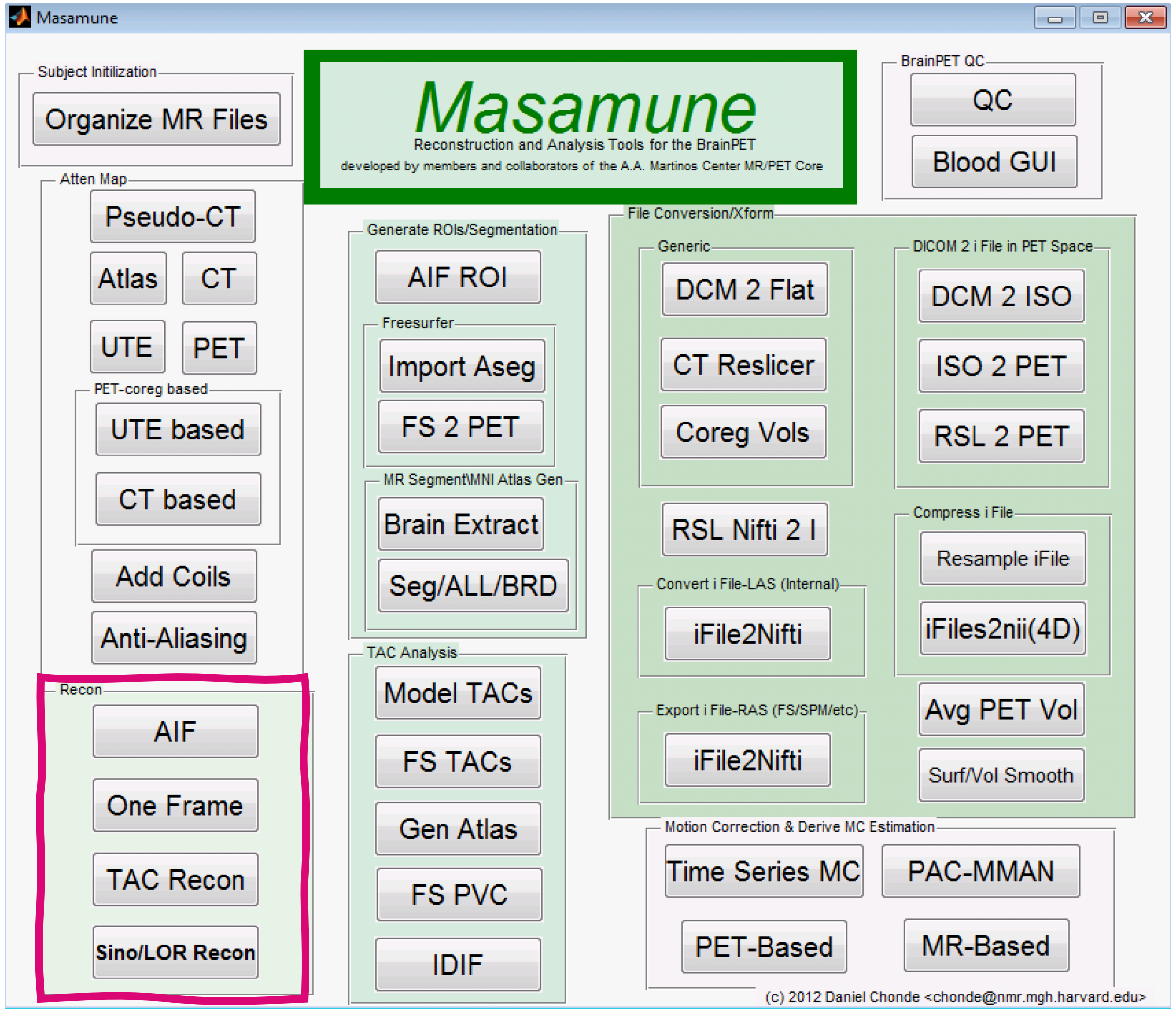
Attenuation correction

Motion correction

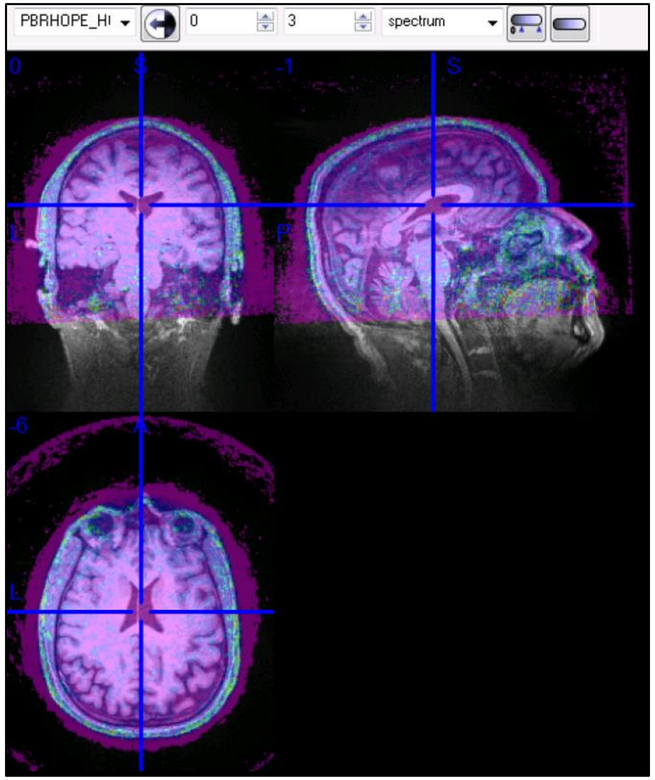


Masamune

http://people.fas.harvard.edu/~kastman/nwlabs_pipeline/pet-recon-mgh.html

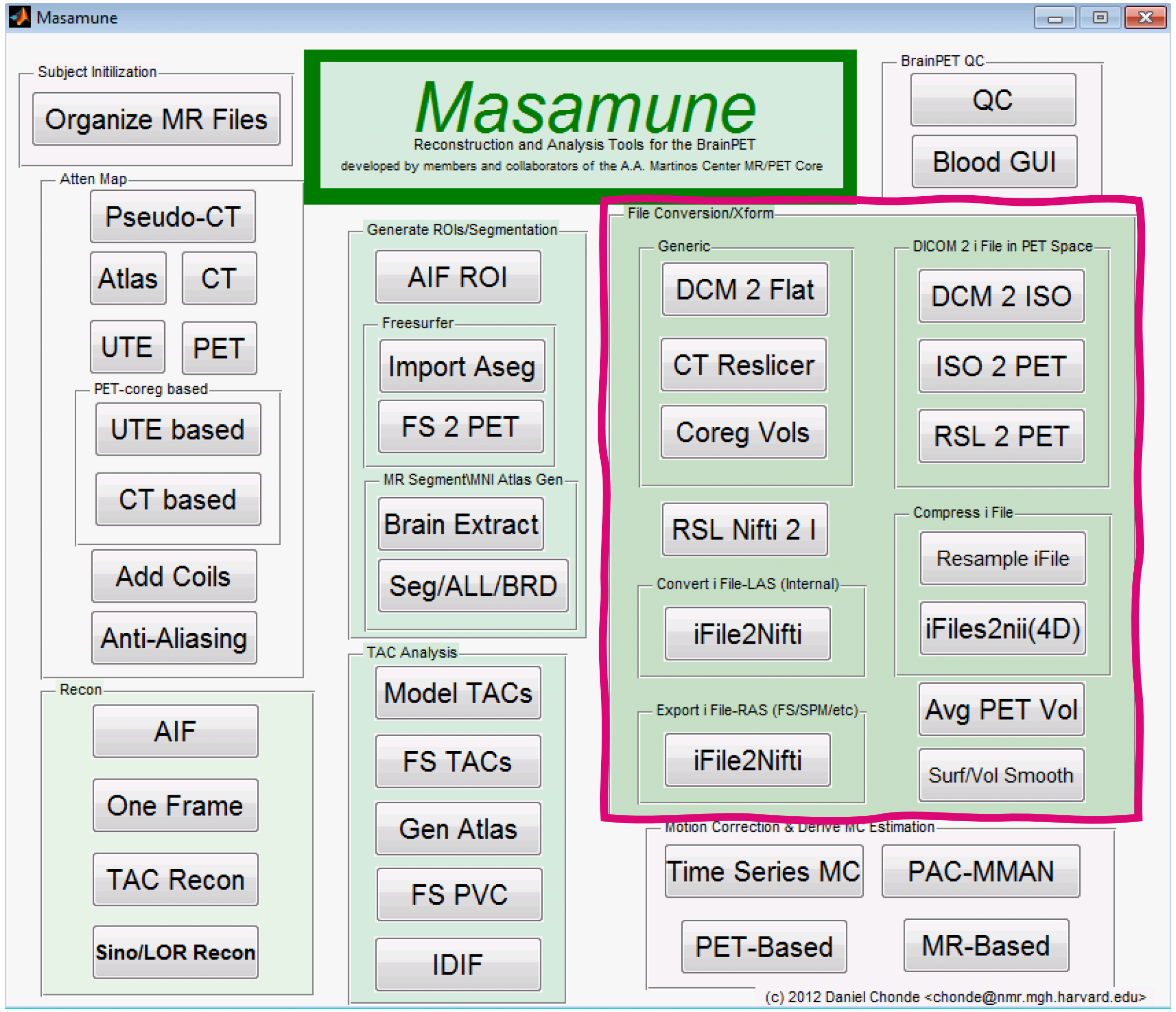


Matlab tool for reconstruction of 'BrainPET' PET-MR data (Bay 6)



Masamune

http://people.fas.harvard.edu/~kastman/nwlabs_pipeline/pet-recon-mgh.html



Matlab tool for reconstruction of 'BrainPET' PET-MR data (Bay 6)

Attenuation correction

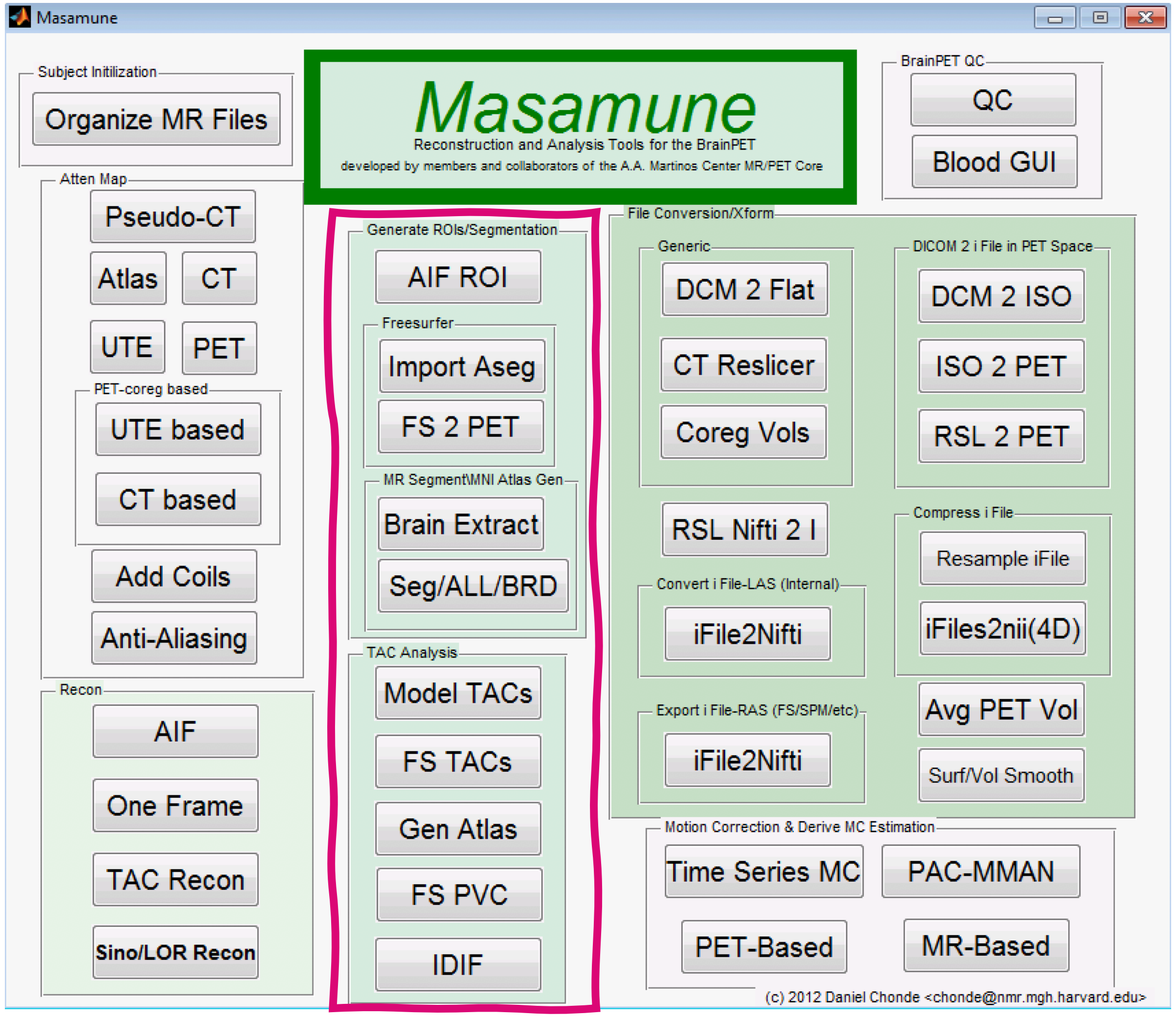
Motion correction

Data reconstruction

File conversion

Masamune

http://people.fas.harvard.edu/~kastman/nwlabs_pipeline/pet-recon-mgh.html



Matlab tool for reconstruction of 'BrainPET' PET-MR data (Bay 6)

Attenuation correction

Motion correction

Data reconstruction

File conversion

ROI segmentation

TAC analysis

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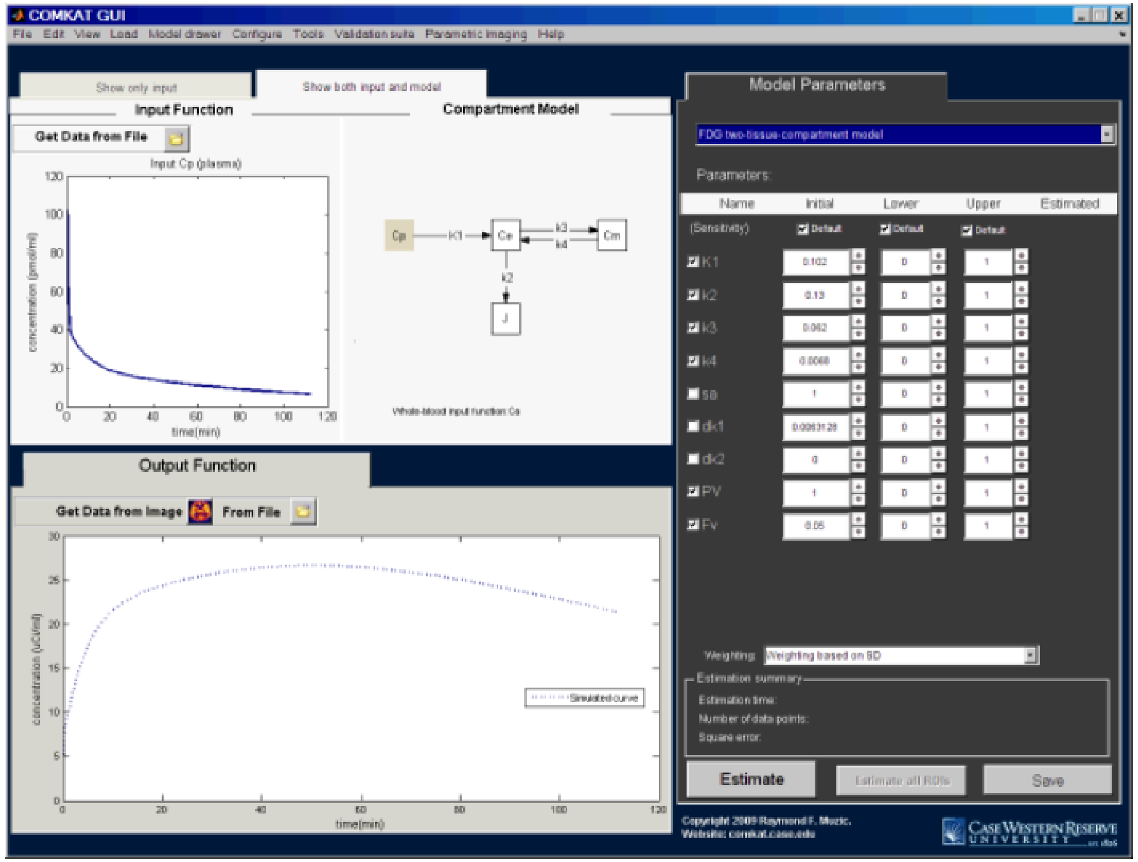
Comkat *(COmpartmental Model Kinetic Analysis Tool)*

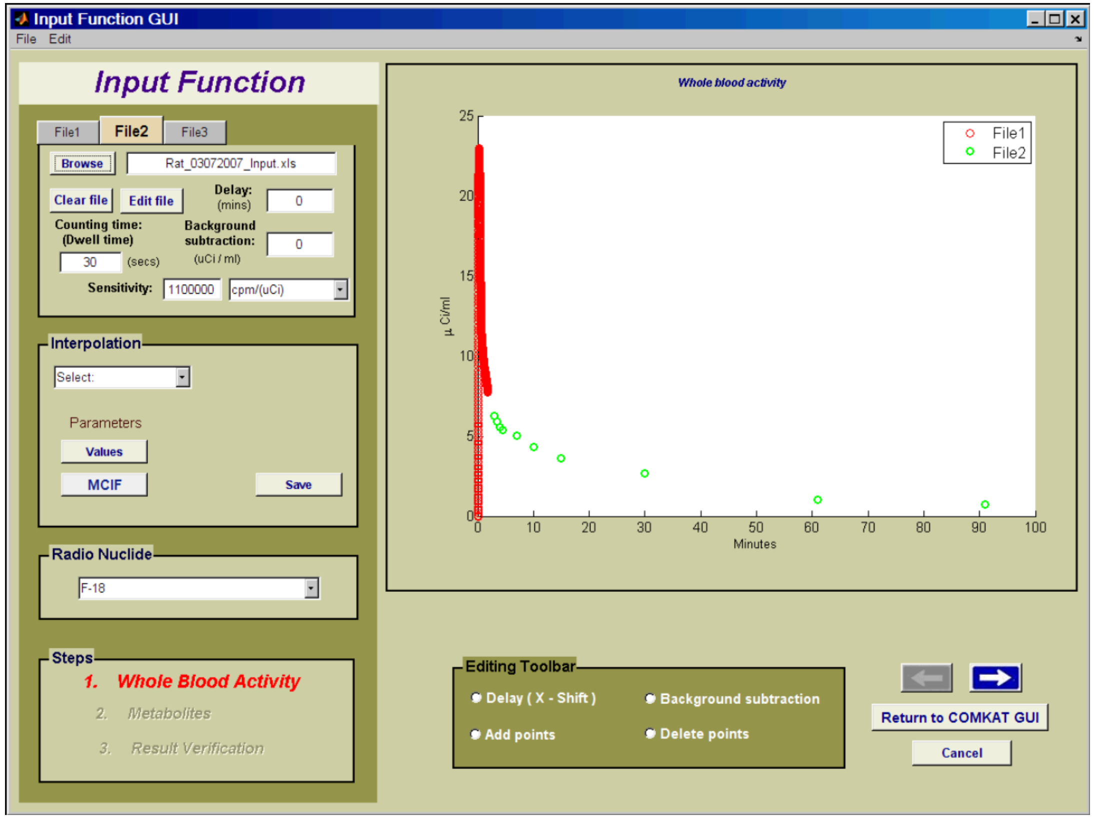


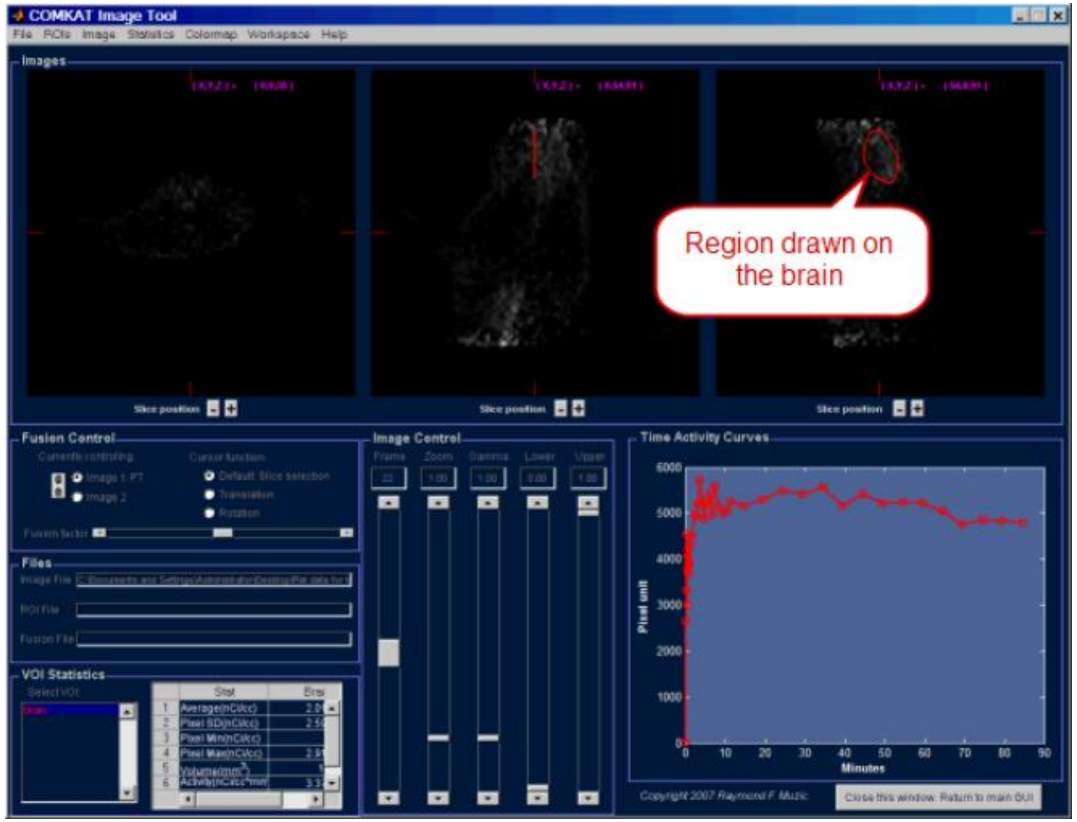
MATLAB software for **compartmental modeling oriented to nuclear medicine applications** (PET & SPECT). It supports models of a wide range complexity including ***multiple injection, receptor model with saturation***:

- It supports **many image formats**, including DICOM
- Using either **the command line interface or GUI**, models are easily specified, solved or used to fit experimental data.
- **No mathematical derivations are required** on the part of the user.

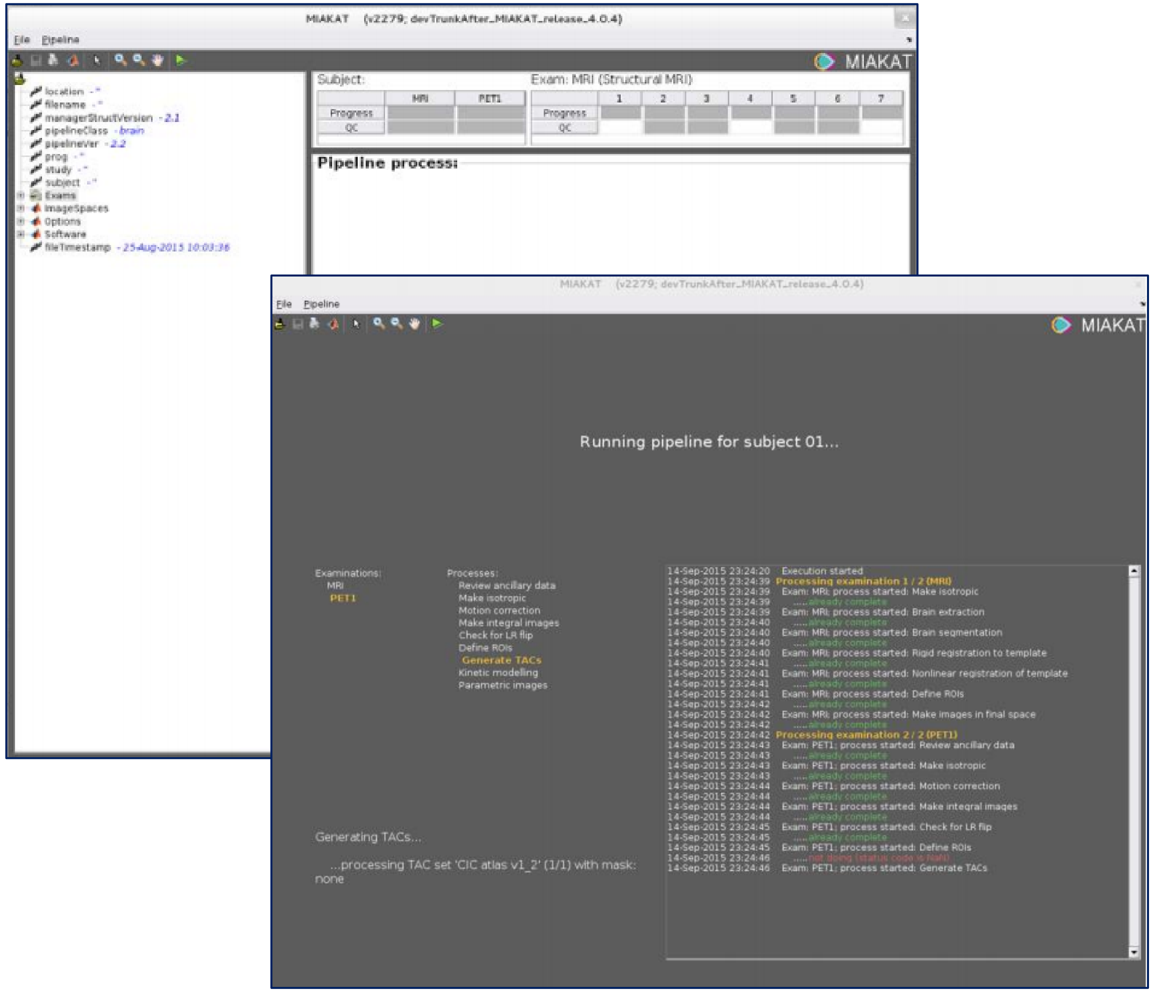
http://comkat.case.edu/

Comkat *(COmpartmental Model Kinetic Analysis Tool)*





MIAKAT



MIAKAT is a **fully quantitative suite of analysis tools for PET neuroimaging data** bringing together state of the art tools in a single user-friendly software environment.

It is implemented in MATLAB and it has a central **GUI that facilitates "point and click" operation.**

The user can **configure an analysis pipeline for a given research study**, and then simply **replicate it for each dataset**.

http://www.miakat.org/

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MIAKAT

STANDARD BRAIN PIPELINE

- take the **primary experimental data** (dynamic PET, structural MR images, arterial blood measurements)
- perform a **sequence of processes** which ultimately produce results in **regional (or voxel-wise) parameters**

Brain Extraction
Brain Tissue Segmentation
Motion Correction
Regional ROI Definition via Atlas
Blood/Plasma Function Modelling
ROI Tracer Kinetic Modelling
Parametric Imaging

http://www.miakat.org/

Overview

Athinoula A. Martinos Center For Biomedical Imaging

- WHAT?
- WHY?
- HOW?
  - ➢ GETTING STARTED
  - ➢ SCRIPTS, FUNCTIONS, AND THE EDITOR
  - ➢ VISUALIZATION TOOLS
- BUT … CAN I STILL USE IT, IF I DON'T want ~~KNOW HOW~~ TO CODE?

Overview

Athinoula A. Martinos Center For Biomedical Imaging

- **WHAT?**
- **WHY?**
- **HOW?**
  - ➢ GETTING STARTED
  - ➢ SCRIPTS, FUNCTIONS, AND THE EDITOR
  - ➢ VISUALIZATION TOOLS
- **BUT … CAN I STILL USE IT, IF I DON'T ~~KNOW HOW~~ want TO CODE?**

Bonus: Miscellaneous "Advanced" Topics

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Martinos
Center
For Biomedical Imaging

Using MATLAB @ Martinos Center

Opening MATLAB

If you are logged into ***any*** Linux workstation in ***Martinos Center***

`$ matlab &` ← opens DEFAULT MATLAB version (**NOT** necessarily the **LATEST** version)

Other versions can be found as well (executable are in **`/usr/pubsw/bin/`**):

```
matlab       matlab7.0    matlab7.11   matlab7.2    matlab7.4    matlab7.7
matlab7.9    matlab8.2    matlab8.4    matlab8.6    matlab9.2    matlab9.4
matlab9.6    matlab.new   matlab6.5.1  matlab7.1    matlab7.14   matlab7.3
matlab7.5    matlab7.8    matlab8.0    matlab8.3    matlab8.5    matlab9.0
matlab9.3    matlab9.5    matlab9.7
```

Using MATLAB from ‘your’ laptop

Use a Network License

This version only works when you are connected to the network inside the Partners firewall.
https://www.nmr.mgh.harvard.edu/intranet/computer/software/matlab (Intranet login required).

Use remote access to your work desktop:

No Machine (software from Partners)

https://www.nmr.mgh.harvard.edu/intranet/computer/remote-access/nomachine

VNC (GUI access to Martinos workstations)

http://www.nmr.mgh.harvard.edu/martinos/userInfo/computer/vnc/windows.php

Standalone License

If you need a copy of Matlab that will work wherever you go **you need to buy a standalone license.** Contact Alyssa Silverman (Alyssa.Silverman@mathworks.com) for a quote and then submit the quote to whomever handles purchasing for your department.

MATLAB & launchpad

The center has limited numbers of MATLAB licenses.

All users are limited to no more than 20 MATLAB licenses in use at once over all locations (launchpad, tensor or your group workstations).

You can run MATLAB jobs in the cluster (launchpad)

http://www.nmr.mgh.harvard.edu/martinos/userInfo/computer/launchpad.php

- Submit any jobs that use MATLAB to the queue **matlab**.
- If your job requires any toolbox licenses, you are limited to just **ONE** such job running on the cluster.
- To automate MATLAB jobs on the cluster, first **create a *.m script file with your actual Matlab commands** to run. The last line of the script should be 'exit'. Give a command like this to **pbsubmit's -c option:**

```
matlab.new -nodisplay -nodesktop -nojvm -r matlabfile
```

- Another option is to "**compile**" your Matlab program into a **stand-alone executable**. ***This will not use up a license normally.*** https://www.nmr.mgh.harvard.edu/martinos/itgroup/deploytool.html

Calling MATLAB from SHELL

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Running MATLAB scripts from SHELL

The MATLAB Editor is nice but:

- Let us assume that you have a **complicated SHELL processing stream** using **FSL & FreeSurfer** tools.
- You want to do a little bit of something in the middle with MATLAB that neither FSL or FS can do.
- Then it is more convenient to **run your MATLAB script from UNIX command line** as part of your main script, without starting an interactive MATLAB session.

```
matlab.new -nodesktop -nodisplay -r "run /full/path/to/script/my_script”
```

NOTE

1. NO *.m extension in the script file name
2. Make sure last line of the file `my_script.m` is `exit;`

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Calling Python (or anything else) from MATLAB

Athinoula A. Martinos Center For Biomedical Imaging

Calling Python from MATLAB

USING THE DEFAULT PYTHON SUB-SYSTEM

- Specific ***only for Python***
- Similar functionalities also available for a handful of other languages

mymod.py

```
"""Python module demonstrates passing
   MATLAB types to Python functions"""

import numpy as np

def square(num):
    num = np.asarray(num)
    return np.power(num,2)

def root(num):
    num = np.asarray(num)
    return np.sqrt(num)
```

matlab_main.m

```
clear
clc

mod = py.importlib.import_module('mymod');
py.reload(mod);

array = 1:10;
array_squared = double(py.mymod.square(array)');
array_root    = double(py.mymod.root(array)');

disp('Array')
disp(array)
disp('Array square')
disp(array_squared)
disp('Array root')
disp(array_root)
```

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Calling Python from MATLAB

USING THE GENERIC SYSTEM CALL

- We can use the **system** call
- Can also do this with scripts from other programming languages

mymod.py

```python
"""Python module demonstrates passing
   MATLAB types to Python functions"""

import numpy as np

def square(num):
    num = np.asarray(num)
    return np.power(num,2)

def root(num):
    num = np.asarray(num)
    return np.sqrt(num)
```

python_main.py

```python
from mymod import square, root
import scipy.io as spio

filename = 'matlab_output.mat'
input = spio.loadmat(filename,
                     struct_as_record=False,
                      squeeze_me=True)

input = input['array']
input_squared = square(input)
input_root = root(input)

spio.savemat('python_output.mat',
              {'square': input_squared,
               'root': input_root})

# print(input_squared)
# print(input_root)
```

matlab_main.m

```matlab
clear
clc

array = 1:10;
save('matlab_output.mat','array');

[status,result] = system('python python_main.py');

python_output = load('python_output.mat');
array_squared = python_output.square';
array_root = python_output.root';

disp('Array')
disp(array)
disp('Array square')
disp(array_squared)
disp('Array root')
disp(array_root)
```

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input_squared = square(input)
input_root = root(input)

spio.savemat('python_output.mat',
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              'root': input_root})

# print(input_squared)
# print(input_root)
```

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```matlab
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clc

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array_root = python_output.root';

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                      squeeze_me=True)

input = input['array']
input_squared = square(input)
input_root = root(input)

spio.savemat('python_output.mat',
             {'square': input_squared,
              'root': input_root})

# print(input_squared)
# print(input_root)
```

matlab_main.m

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clear
clc

array = 1:10;
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input = spio.loadmat(filename,
                     struct_as_record=False,
                      squeeze_me=True)

input = input['array']
input_squared = square(input)
input_root = root(input)

spio.savemat('python_output.mat',
             {'square': input_squared,
              'root': input_root})

# print(input_squared)
# print(input_root)
```

matlab_main.m

```matlab
clear
clc

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save('matlab_output.mat','array');

[status,result] = system('python python_main.py');

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array_squared = python_output.square';
array_root = python_output.root';

disp('Array')
disp(array)
disp('Array square')
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disp('Array root')
disp(array_root)
```

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Calling Python from MATLAB

USING THE GENERIC SYSTEM CALL

- We can use the **system** call
- Can also do this with scripts from other programming languages

Don't do this

if you just need Python, but …

mymod.py

```
"""Python module demonstrates passing
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import numpy as np

def square(num):
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python_main.py

```
from mymod import square, root
import scipy.io as spio

filename = 'matlab_output.mat'
input = spio.loadmat(filename,
            struct_as_record=False,
            squeeze_me=True)

input = input['array']
input_squared = square(input)
input_root = root(input)

spio.savemat('python_output.mat',
      {'square': input_squared,
       'root': input_root})

# print(input_squared)
# print(input_root)
```

matlab_main.m

```
clear
clc

array = 1:10;
save('matlab_output.mat','array');

[status,result] = system('python python_main.py');

python_output = load('python_output.mat');
array_squared = python_output.square';
array_root = python_output.root';

disp('Array')
disp(array)
disp('Array square')
disp(array_squared)
disp('Array root')
disp(array_root)
```

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Executing UNIX commands from MATLAB

USING THE GENERIC SYSTEM CALL

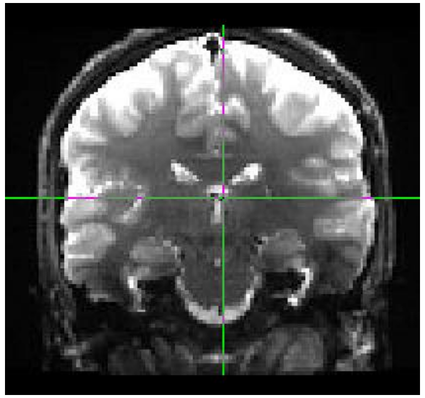
What if I need an **FSL command** in the middle of an elaborate MATLAB processing pipeline?

```
% < Do some preprocessing, and save results
%   somewhere on disk. >

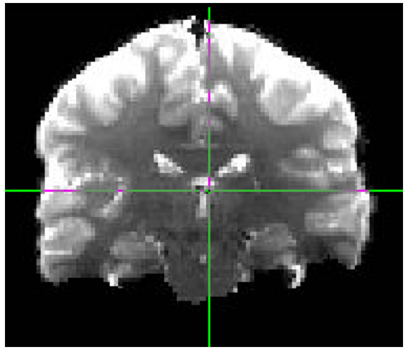
% MAKE A STRING FOR THE FSL BET COMMAND
command_string_bet = 'bet b0.nii.gz b0_brain.nii.gz -m';

% EXECUTE THE FSL COMMAN USING SYSTEM
[status,result] = system(command_string_bet);

% < Load back the results and continue ... >
```



b0



b0_brain

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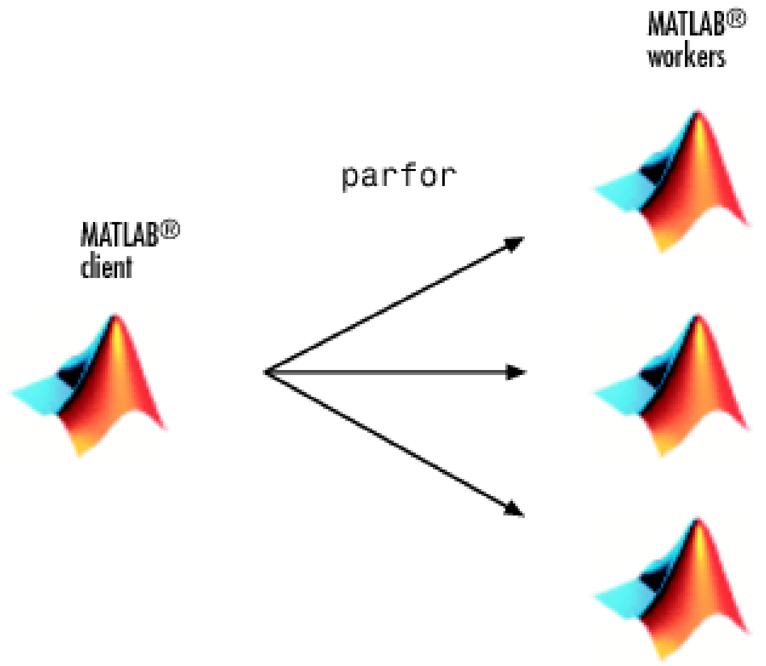
For Biomedical Imaging

Speeding-up your code

- **Use functions** instead of scripts.
- **Pre-allocate** the final size of arrays.
- **Vectorize**: Instead of writing loop-based code, consider using MATLAB matrix and vector operations.
- Place independent operations outside loops.
- **Avoid** programmatic use of ***cd, addpath***, and ***rmpath***, when possible: *changing the MATLAB path during run time results in code recompilation.*

Parallel computing toolbox

USING PARALLEL FOR-LOOP (PARFOR)




```
n = 2000;
A = 500;

a = zeros(1,n);
tStart = tic;
for i = 1:n
    a(i) = max(abs(eig(rand(A))));
end
tEnd = toc(tStart);
fprintf('Standard FOR loop:\n%d minutes and %.2f seconds\n',...
    floor(tEnd/60), rem(tEnd,60));
```

```
Standard FOR loop:
5 minutes and 44.89 seconds
```

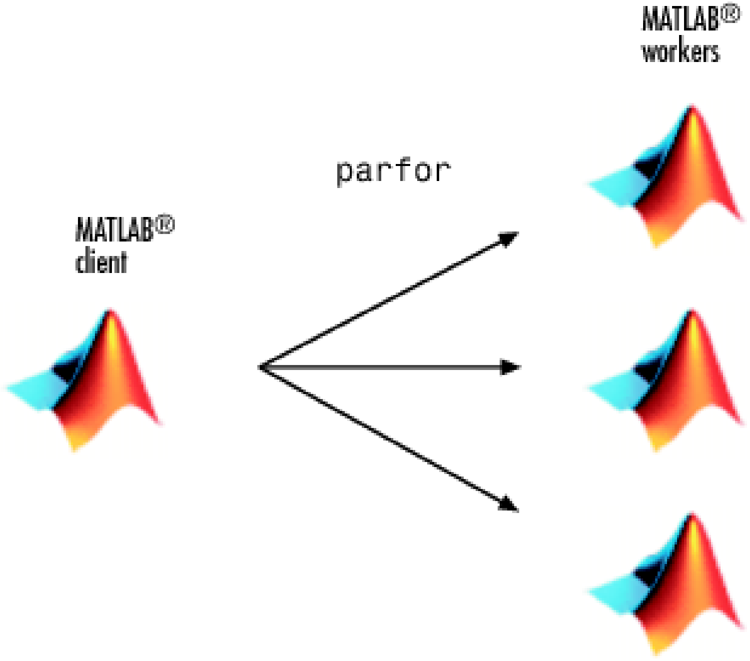
```
a = zeros(1,n);
tStart = tic;
parfor i = 1:n
    a(i) = max(abs(eig(rand(A))));
end
tEnd = toc(tStart);
fprintf('Parallel PARFOR loop:\n%d minutes and %.2f seconds\n',...
    floor(tEnd/60), rem(tEnd,60));
```

```
Parallel PARFOR loop:
1 minutes and 44.28 seconds
```

N.B. You cannot call scripts directly in a parfor-loop. However, you can call functions.

Parallel computing toolbox

USING PARALLEL FOR-LOOP (PARFOR)




```
n = 2000;
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    a(i) = max(abs(eig(rand(A))));
end
tEnd = toc(tStart);
fprintf('Standard FOR loop:\n%d minutes and %.2f seconds\n',...
```

```
Standard FOR loop:
5 minutes and 44.89 seconds
```

```
a = zeros(1,n);
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    a(i) = max(abs(eig(rand(A))));
end
tEnd = toc(tStart);
```

```
Parallel PARFOR loop:
1 minutes and 44.28 seconds
```

N.B. You cannot call scripts directly in a parfor-loop. However, you can call functions.

Parallel computing toolbox

USING PARALLEL FOR-LOOP (PARFOR)

DO use 'parfor' loops	DON'T use 'parfor' loops
• many loop iterations of a **simple calculation** • Loop iterations are "**independent**"	• **An iteration** in your loop **depends on the results of other** iterations • You plan of using the *matlab* queue on ***launchpad*** • There's no Parallel Computation TOOLBOX **license** available …

MATLAB Executable (MEX) File Functions

CALL C/C++ OR FORTRAN MEX FILE FUNCTIONS FROM MATLAB

MEX stands for **M**ATLAB **EX**ecutable.

A MEX file is **a function**, created in MATLAB, **that calls a C/C++ program or a Fortran subroutine**. A MEX function behaves just like a MATLAB script or function.

Two main components:

- A gateway routine, **mexFunction**, that interfaces C/C++ and MATLAB data
- Some *non-MATLAB* source code, that performs the desired computations

```
void mexFunction(
    int nlhs, mxArray *plhs[],
    int nrhs, const mxArray *prhs[])
{
    /* more C code ... */
}
```

PROS

Fast calculations

~~Easy to learn and use~~

CONS

Slow implementation compared to M-files

Platform dependent (re)compilation

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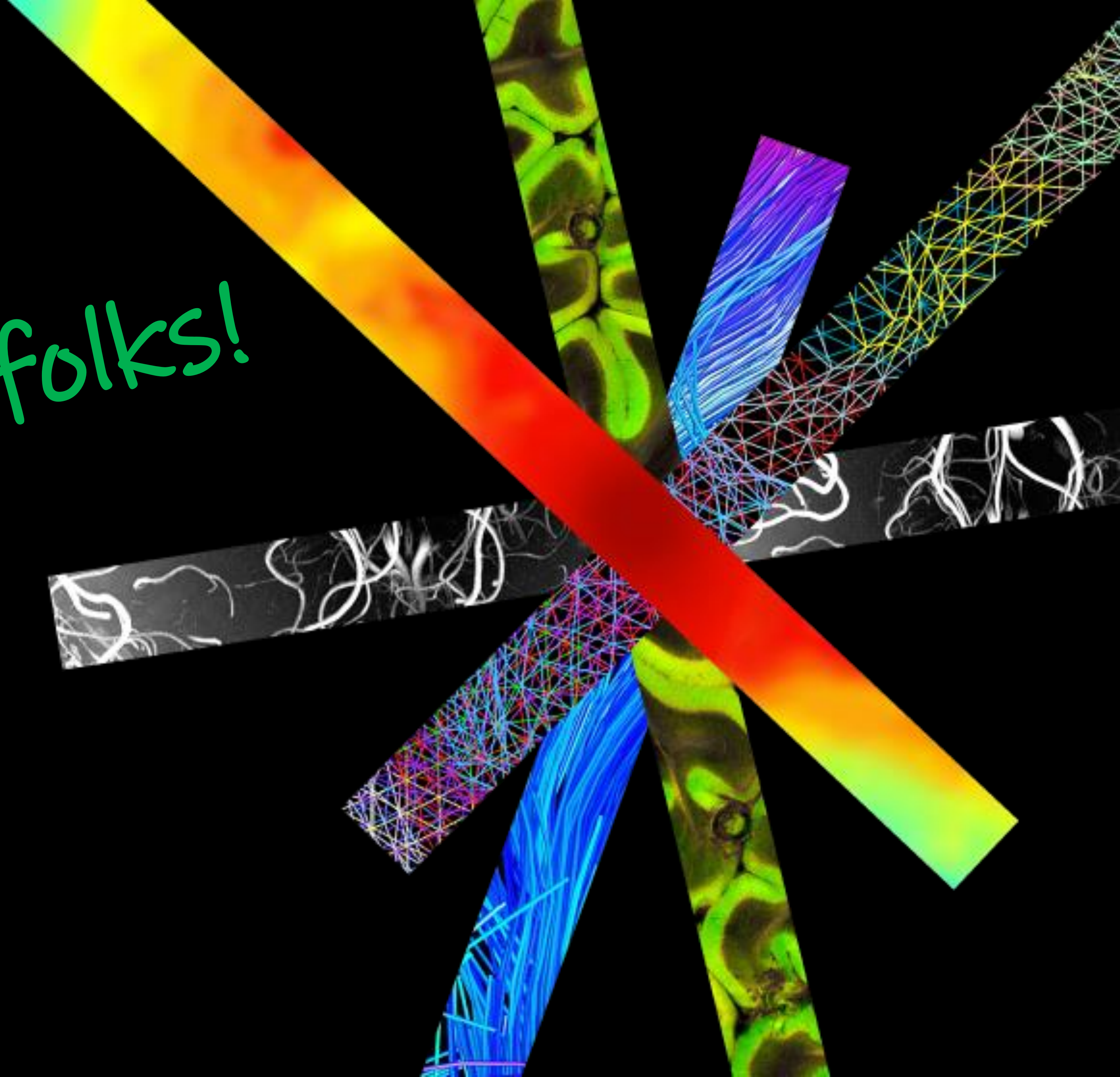
Martinos Center
For Biomedical Imaging

That's all folks!



Thanks for joining!

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